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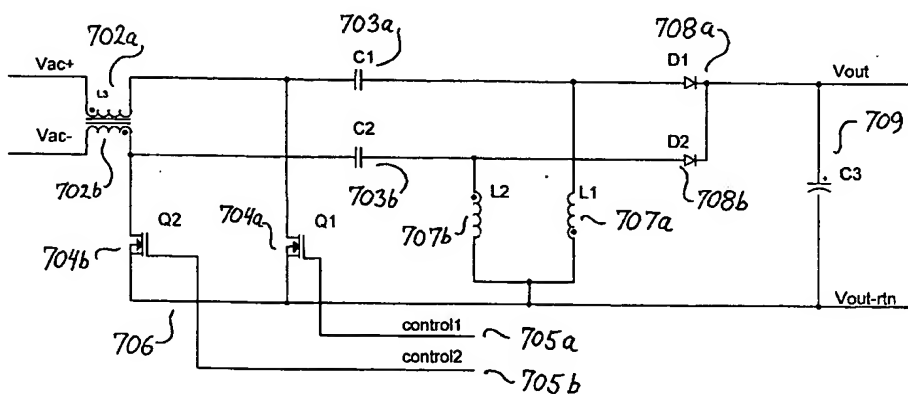
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(54) Title: AC-DC CONVERTER WITH NO INPUT RECTIFYING DIODE BRIDGE



(57) Abstract: An AC-DC power converter having no input rectifiers is provided. This is obtained by a power converter, which comprises a primary circuit for coupling to an AC voltage source via a first AC input and a second AC input, and with an output having a first forward path, a second forward path and a return path. The converter also comprises a secondary circuit with an input having a first forward path, a second forward path and a return path for receiving power via the corresponding output paths of the primary circuit, and with first and second outputs for delivering a DC power to a load. The primary circuit comprises a first current path between the first AC input and a first output end, a second current path between the second AC input and a second output end, a first power switch, a second power switch, a first coupling capacitor with first and second terminals, a second coupling capacitor with first and second terminals, a first input inductor being arranged in the first current path between the first AC input and the first output end and/or a second input inductor being arranged in the second current path between the second AC input and the second output end. Preferred embodiments include a so-called double SEPIC configuration, a so-called double CUK configuration and a so-called AC-HYBRIDGE configuration.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

## AC-DC CONVERTER WITH NO INPUT RECTIFYING DIODE BRIDGE

## FIELD OF THE INVENTION

- 5 The present invention relates to AC-DC switching power converters, and in particular to converter configurations without any input rectifying diode bridge.

## BACKGROUND OF THE INVENTION

- 10 A very common need in electronics is converting AC powerline energy to DC power to supply an electronic circuit as a load. In addition, it is often necessary to regulate the DC power in order to maintain the load voltage approximately constant in spite of variations in the powerline voltage and the load current. Series regulators, which in effect are controllable resistances in series with the load, have given place, in  
15 many applications, to switching regulators. In these regulators, the powerline voltage is rectified to DC, which is then switched into various inductors and capacitors at a frequency many times higher than the powerline frequency. These reactances alternately absorb powerline energy and deliver it to the load in a manner, which may be controlled to provide constant load voltage.

- 20 Standard switching regulator topologies include the buck regulator, in which the output DC voltage is less than the input voltage, and the boost regulator, in which the output voltage is higher than the input voltage. The single ended primary inductance converter, SEPIC, is a more recent topology which uses two inductors and which  
25 has the advantage of allowing the output voltage to be either higher or lower than the input voltage. Another more recent topology is the CUK converter which also uses two inductors, but which uses a capacitive energy transfer. The CUK converter also has the advantage of allowing the output voltage to be either higher or lower than the input voltage.

- 30 However, all of the above mentioned switching regulator topologies use input rectifiers, which may have the form of a full wave bridge, and which may contribute significantly to losses in the converter.

An AC-DC converter with no input rectifiers is disclosed in US Patent No. 6,115,267. However, the converter topology disclosed in US 6,115,267 is a transformer isolated topology having a main power path which is buck-derived.

- 5 Thus, there is a need for an AC-DC converter topology, which has no input rectifiers, thereby reducing power losses in the converter, which allows for converters without transformer isolation, and which allows for a greater variation in the output voltage. The present invention provides a solution for such a converter topology.

## 10 SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided an AC-DC power converter having no input rectifiers, said power converter comprising:

- 15 a primary circuit for coupling to an AC voltage source via a first AC input and a second AC input, and with an output having a first forward path, a second forward path and a return path, and  
a secondary circuit with an input having a first forward path, a second forward path and a return path for receiving power via the corresponding output paths of the primary circuit, and with first and second outputs for delivering a DC power to a load,  
20

wherein said primary circuit comprises:

- 25 a first current path between the first AC input and a first output end, a second current path between the second AC input and a second output end, a first power switch, a second power switch, a first coupling capacitor with first and second terminals, a second coupling capacitor with first and second terminals, a first input inductor being arranged in the first current path between the first AC input and the first output end and/or a second input inductor being arranged in the second current path  
30 between the second AC input and the second output end,

- means for providing a current path from the return path to the second output end during at least part of a period of positive AC input voltage, during which period the input voltage at the first AC input is positive compared to the voltage of the second  
35 AC input, and

means for providing a current path from the return path to the first output end during at least part of a period of negative AC input voltage, during which period the input voltage at the first AC input is negative compared to the voltage of the second AC input,

5

said first power switch and said first coupling capacitor being arranged so that when the first switch is on, a current can flow from the first AC input, via the first current path, through the first switch and into the return path, and so that when the first switch is off, a current can flow from the first AC input, through the first current path and into the first coupling capacitor via the first terminal of the first coupling capacitor, said first coupling capacitor being arranged so that a current can flow from its second terminal, via the first forward path of the primary circuit and into the first forward path of the secondary circuit, and

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said second power switch and said second coupling capacitor being arranged so that when the second switch is on, a current can flow from the second AC input, via the second current path, through the second switch and into the return path, and so that when the second switch is off, a current can flow from the second AC input, through the second current path and into the second coupling capacitor via the first terminal of the second coupling capacitor, said second coupling capacitor being arranged so that a current can flow from its second terminal, via the second forward path of the primary circuit and into the second forward path of the secondary circuit.

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In a preferred embodiment of the invention, the first power switch has a first terminal, a second terminal and a control terminal, and the second power switch has a first terminal, a second terminal and a control terminal,

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said first output end being coupled to the first terminal of the first switch and the first terminal of the first coupling capacitor, the second terminal of the first switch being coupled to the return path, and the control terminal of the first switch being coupled to means for controlling the first power switch in the on and off states, and said second output end being coupled to the first terminal of the second switch and the first terminal of the second coupling capacitor, the second terminal of the second switch being coupled to the return path, and the control terminal of the second switch being coupled to means for controlling the second power switch in the on and off states.

35

According to the first aspect of the present invention, there is also provided an AC-DC power converter having no input rectifiers, said power converter comprising:

- 5 a primary circuit for coupling to an AC voltage source via a first AC input and a second AC input, and with an output having a first forward path, a second forward path and a return path, and  
a secondary circuit with an input having a first forward path, a second forward path and a return path for receiving power via the corresponding output paths of the primary circuit, and with first and second outputs for delivering a DC power to a load,  
10

wherein said primary circuit comprises:

- a first current path between the first AC input and a first output end, a second current path between the second AC input and a second output end, a first power  
15 switch with a first terminal, a second terminal and a control terminal, a second power switch with a first terminal, a second terminal and a control terminal, a first coupling capacitor with first and second terminals, a second coupling capacitor with first and second terminals, a first input inductor being arranged in the first current path between the first AC input and the first output end and/or a second input inductor being  
20 arranged in the second current path between the second AC input and the second output end,

- means for providing a current path from the return path to the second output end during at least part of a period of positive AC input voltage, during which period the  
25 input voltage at the first AC input is positive compared to the voltage of the second AC input, and

- means for providing a current path from the return path to the first output end during at least part of a period of negative AC input voltage, during which period the input  
30 voltage at the first AC input is negative compared to the voltage of the second AC input,

- said first output end being coupled to the first terminal of the first switch and the first terminal of the first coupling capacitor, the second terminal of the first switch being  
35 coupled to the return path of the primary circuit, the control terminal of the first



switch being coupled to control means for controlling the first switch in on and off states for conducting current between the first and second terminals of the first switch, the second terminal of the first coupling capacitor being coupled to the first forward path of the primary circuit, and

5

said second output end being coupled to the first terminal of the second switch and the first terminal of the second coupling capacitor, the second terminal of the second switch being coupled to the return path of the primary circuit, and the control terminal of the second switch being coupled to control means for controlling the second switch in on and off states for conducting current between the first and second terminals of the second switch, the second terminal of the second coupling capacitor being coupled to the second forward path of the primary circuit.

10

According to a preferred embodiment of the invention, electrical power can be transferred from the primary circuit to the secondary circuit via coupling capacitors only, said power transferring coupling capacitors including the first and second coupling capacitors. Here, the electrical power may be transferred from the primary circuit to the secondary circuit via the first and second coupling capacitors only.

15

However, it is also within an embodiment of the invention that one or more primary coupling capacitors are electrically coupled in parallel to the first coupling capacitor, and/or one or more secondary coupling capacitors are electrically coupled in parallel to the second coupling capacitor. Here, one or more primary coupling capacitors may have their first and second terminals electrically coupled to the first and second terminals, respectively, of the first coupling capacitor, and/or one or more secondary coupling capacitors may have their first and second terminals electrically coupled to the first and second terminals, respectively, of the second coupling capacitor. Thus, it is within a preferred embodiment that electrical power can be transferred from the primary circuit to the secondary circuit only via the first and second coupling capacitors and said primary and/or secondary coupling capacitors.

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The present invention also covers embodiments in which the AC-DC power converter further comprises means for controlling the first and second power switches so that the first power switch is turned on and off a plurality of times during each period

of a positive AC input voltage, and so that the second power switch is turned on and off a plurality of times during each period of a negative AC input voltage.

5 It is preferred that each power switch is a N-channel MOSFET transistor having a drain terminal as the first terminal, a source terminal as the second terminal and a gate terminal as the control terminal.

10 Embodiments of the AC-DC power converter of the present invention may further comprise means for controlling the first and second power switches so that the second power switch is turned on during periods of a positive AC input voltage thereby providing a current path from the return path of the primary circuit to the second output end of the second current path, and so that the first power switch is turned on during periods of negative AC input voltage, thereby providing a current path from the return path of the primary circuit to the first output end of the first current path.

15 For converters having N-channel MOSFET transistors the control terminals of the first switch and the second switch may be controlled by a single output signal from the means for controlling the first and second power switches, whereby the second switch is conducting as a rectifying diode for periods of positive AC input voltage  
20 when the second switch is off thereby providing a current path from the return path to the second output end, and the first switch is conducting as a rectifying diode for periods of negative AC input voltage when the first switch is off thereby providing a current path from the return path to the first output end.

25 However, it is also within embodiments of the present invention that a first input rectifier has an output coupled to the first output end and to the first terminal of the first coupling capacitor and has an input coupled to the return path of the primary circuit, and a second input rectifier has an output coupled to the second output end and to the second terminal of the second coupling capacitor and has an input coupled to  
30 the return path of the primary circuit, whereby the first rectifier provides a current path from the return path to the first output end during periods of positive AC input voltage, and the second rectifier provides a current path from the return path to the second output end during periods of negative AC input voltage.

Preferably, the means for controlling the first and the second power switches between on and off is adapted to use pulse width modulation. Here, it is further preferred that the means for controlling the first and the second power switches between on and off is adapted to control the power switches for power factor correction, whereby the input current received from the AC input voltage source is controlled to substantially follow a sine wave.

The present invention covers embodiments in which a first input inductor is arranged in the first current path and no inductor is arranged in the second current path. In alternative embodiments, no inductor is arranged in the first current path, while a second input inductor is arranged in the second current path. However, it is preferred that the converter has both a first input inductor and a second input inductor. Here, the first and second input inductors may be magnetically coupled.

For embodiments of the invention having both the first and the second input inductors, it is preferred that the first input inductor has a first terminal and a second terminal and the second input inductor has a first terminal and a second terminal, the first terminal of the first inductor being coupled to the first AC input and the second terminal of the first inductor being coupled to the first output end, the second terminal of the second inductor being coupled to the second AC input and the first terminal of the second inductor being coupled to the second output end. Alternatively, the second terminal of the first inductor may be coupled to the first AC input with the first terminal of the first inductor being coupled to the first output end, and the first terminal of the second inductor may be coupled to the second AC input with the second terminal of the second inductor being coupled to the second output end.

According to a second aspect of the present invention the secondary circuit of the embodiments of the invention described above may comprise:  
an output capacitor having a first positive terminal coupled to the first output and a second negative terminal coupled to the second output,  
a first output rectifier and a first output inductor coupled in series between the first and the second terminals of the output capacitor for transferring power received via the first forward path to the output capacitor, and  
a second output rectifier and a second output inductor coupled in series between the first and the second terminals of the output capacitor for transferring power received

via the second forward path to the output capacitor. Here the first and the second output rectifiers may have current output ends coupled to the first positive terminal of the output capacitor, and the output inductors may be coupled to the second negative terminal of the output capacitor.

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In a first preferred embodiment of the second aspect of the invention, the first forward path of the secondary circuit is coupled to an input end of the first output rectifier and one end of the first output inductor, said first output rectifier having an output end coupled to the first terminal of the output capacitor and said first output inductor having the other end coupled to the second terminal of the output capacitor and the return path of the secondary circuit, and

10 the second forward path of the secondary circuit is coupled to an input end of the second output rectifier and one end of the second output inductor, said second output rectifier having an output end coupled to the first terminal of the output capacitor and said second output inductor having the other end coupled to the second terminal of the output capacitor and the return path of the secondary circuit.

15

In a second preferred embodiment of the second aspect of the invention, the first forward path of the secondary circuit is coupled to an input end of the first output rectifier and one end of the first output inductor, said first output inductor having the other end coupled to the second terminal of the output capacitor and said first output rectifier having an output end coupled to the first terminal of the output capacitor and the return path of the secondary circuit, and

20 the second forward path of the secondary circuit is coupled to an input end of the second output rectifier and one end of the second output inductor, said second output inductor having the other end coupled to the second terminal of the output capacitor and said second output rectifier having an output end coupled to the first terminal of the output capacitor and the return path of the secondary circuit.

25

30 It is also within embodiments of the present invention that the first input and output inductors are magnetically coupled to each other and the second input and output inductors are magnetically coupled to each other. Here, one or more integrated magnetic components may be used for obtaining said magnetic coupling.

According to a third preferred embodiment of the second aspect of the invention the secondary circuit further comprises a first transformer having a primary winding and a secondary winding, and a second transformer having a primary winding and a secondary winding, said primary winding of the first transformer having one end  
5 coupled to the first forward path of the secondary circuit and the other end coupled to the return path of the secondary circuit, said primary winding of the second transformer having one end coupled to the second forward path of the secondary circuit and the other end coupled to the return path of the secondary circuit. Here, each transformer winding may have a first terminal and a second terminal, said terminals  
10 of the first primary windings being arranged so that when the first terminal of the primary winding of the first transformer is coupled to the return path, the second terminal of the primary winding of the second transformer is coupled to the return path, or so that when the second terminal of the primary winding of the first transformer is coupled to the return path, the first terminal of the primary winding of the  
15 second transformer is coupled to the return path. The secondary winding of the first transformer may form the first output inductor, and the secondary winding of the second transformer may form the second output inductor.

When the first transformer and the first output inductor are separate and when the  
20 second transformer and the second output inductor are separate, the secondary circuit according to the third preferred embodiment of the second aspect of the invention may further comprise a third coupling capacitor with first and second terminals and a fourth coupling capacitor with first and second terminals,  
said secondary winding of the first transformer having one end coupled to the first  
25 terminal of the third coupling capacitor and the other end coupled to the first terminal of the output capacitor,  
said secondary winding of the second transformer having one end coupled to the first terminal of the fourth coupling capacitor and the other end coupled to the first terminal of the output capacitor,  
30 said second terminal of the third coupling capacitor being coupled to an input end of the first output rectifier and one end of the first output inductor, said first output inductor having the other end coupled to the second terminal of the output capacitor, and said first output rectifier having an output end coupled to the first terminal of the output capacitor, and

5 said second terminal of the fourth coupling capacitor being coupled to an input end of the second output rectifier and one end of the second output inductor, said second output inductor having the other end coupled to the second terminal of the output capacitor, and said second output rectifier having an output end coupled to the first terminal of the output capacitor.

10 According to a fourth preferred embodiment of the second aspect of the invention the secondary circuit further comprises a third transformer having a primary winding and a secondary winding, a third power switch with a first terminal, a second terminal and a control terminal, and a fourth power switch with a first terminal, a second terminal and a control terminal,

15 said primary winding of the third transformer having one end coupled to the first forward path of the secondary circuit and the other end coupled to the second forward path of the secondary circuit,

20 said third power switch having the first terminal coupled to the first forward path of the secondary circuit, the second terminal coupled to the return path of the secondary circuit, and the control terminal coupled to means for controlling the third power switch in on and off states,

25 said fourth power switch having the first terminal coupled to the second forward path of the secondary circuit, the second terminal coupled to the return path of the secondary circuit, and the control terminal coupled to means for controlling the fourth power switch in on and off states,

30 said secondary winding of the third transformer having one end coupled to an input end of the first output rectifier and one end of the first output inductor, said first output rectifier having an output end coupled to the first terminal of the output capacitor and said first output inductor having the other end coupled to the second terminal of the output capacitor, and

35 said secondary winding of the third transformer having the other end coupled to an input end of the second output rectifier and one end of the second output inductor, said second output rectifier having an output end coupled to the first terminal of the output capacitor and said second output inductor having the other end coupled to the second terminal of the output capacitor. Here, each of the third and fourth power switches may be a P-channel MOSFET transistor having a drain terminal as the first terminal, a source terminal as the second terminal and a gate terminal as the control terminal. Preferably, the AD-DC power converter further comprises means for con-

trolling the third and fourth power switches so that the third power switch is turned on and off a plurality of times during each period of a positive AC input voltage, and so that the fourth power switch is turned on and off a plurality of times during each period of a negative AC input voltage. Here, it is preferred that the means for controlling the third and fourth power switches are adapted to control the third and fourth power switches so that for a positive input voltage the fourth power switch is constant off and the third power switch is conducting when the first power switch is in an off period, and so that for a negative input voltage the third power switch is constant off and the fourth power switch is conducting when the second power switch is in an off period.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the present invention will become more readily apparent upon reference to the following detailed description of preferred embodiments of the invention, when taken in conjunction with the accompanying drawings in which:

Fig. 1 shows the input voltage and input current waveforms for an AC-DC converter without power factor correction, PFC,

Fig. 2 shows the input voltage and input current waveforms for an AC-DC converter with power factor correction, PFC,

Fig. 3 shows a prior art AC-DC converter using a boost topology and having a rectifying diode bridge in the AC input,

Fig. 4 is a block diagram showing a non-isolated AC-DC converter having a power factor correction control circuit and being followed by a DC-DC converter,

Fig. 5 is a block diagram showing an isolated AC-DC converter having a power factor correction control circuit,

Fig. 6 shows a prior art DC-DC converter of the SEPIC topology,

Fig. 7 shows an embodiment of an AC-DC converter according to the present invention using a SEPIC topology,

5 Figs. 8a-8c are waveform diagrams illustrating voltage waveforms occurring in the converter of Fig. 7,

Fig. 9 is a waveform diagram illustrating current waveforms of the input inductor of the converter of Fig. 7,

10 Fig. 10 shows an AC-DC converter having the same topology as the converter of Fig. 7, but using integrated magnetic components,

Fig. 11 shows a transformer isolated version of the AC-DC converter of Fig. 7,

15 Fig. 12 shows a prior art DC-DC converter of the CUK topology,

Fig. 13 shows an embodiment of an AC-DC converter according to the present invention using a CUK topology,

20 Fig. 14 shows an AC-DC converter having the same topology as the converter of Fig. 13, but using integrated magnetic components,

Fig. 15 shows a transformer isolated version of the AC-DC converter of Fig. 13,

25 Fig. 16 shows an embodiment of an AC-DC converter according to the present invention using a Hybridge topology,

Figs. 17a-17c are waveform diagrams illustrating voltage waveforms occurring in the converter of Fig. 16,

30

Fig. 18 shows an embodiment of a primary circuit of an AC-DC converter according to the present invention,

35 Fig. 19 illustrates input current waveforms of an AC-DC converter based on the topology of the converter shown in Fig. 10,



Fig. 20 illustrates voltage waveforms of power switches of the AC-DC converter of Fig. 19,

5 Fig. 21 illustrates voltage waveforms of a power switch and a corresponding output rectifier of the AC-DC converter of Fig. 19, and

Fig. 22 illustrates output voltage ripple of the AC-DC converter of Fig. 19.

## 10 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

"Power factor correction" (PFC) techniques are used to realise AC-DC power converters, which draw input currents having a low harmonic content. There are several reasons for power factor correction. First, there is the limitation on the input current  
15 available, caused by the dimension on the input cores and the system. This was the originally reason for the introduction of power factor correction. Secondly there is the requirement from the standard EN – 61000 – 3 – 2 on the harmonic current drawn on the input power inlets.

20 The reason for these harmonic requirements are to minimise the losses in the public power system and to limit the distortion in the input voltage caused by the high peak current drawn in a standard converter with a input bridge rectifier and a hold up capacitor. This is illustrated in Fig. 1, which shows the input voltage and input current waveforms for an AC-DC converter without power factor correction, PFC.

25 The use of a power factor correcting control circuit is intended to shape the input current as the input voltage, creating a resistive loading for the public power system. This is illustrated in Fig. 2, which shows the input voltage and input current waveforms for an AC-DC converter with power factor correction, PFC.

30 Fig. 3 shows a prior art AC-DC converter 301 using a boost topology and having a rectifying diode bridge in the AC input and having a PFC control circuit. Here, D1 is a diode bridge 302 used for rectifying the bipolar input voltage, Q1 is an input current limiter 303 being controlled by an inrush control circuit 304, C2 is a capacitor  
35 305 used for boost input filtering, L1 is a boost inductor 306, Q2 is a boost switch

307 providing pulse width modulated excitation of the inductor L1 and being controlled by a PFC control circuit 308, D2 is a boost rectifying diode 309, and C3 is a boost output capacitor 310. The DC output from the output capacitor C3 is feed into a standard DC-DC converter 311 providing an output voltage, which may be feed to a load. The purpose of the DC-DC converter 311 is to eliminate or reduce the ripple in the output signal, as the DC signal received via the output capacitor C3 contains an amount of ripple due to the power factor correction. The DC-DC converter 311 may further provide a required isolation between the AC input and the DC output and the converter may provide a desired output voltage level.

In the prior art it is normal to use a rectifying diode bridge followed by a boost converter in connection with a power factor correction circuit. The converter 301 of Fig. 3 further has an active element placed in the current path to limit the current in the booster during bus plug in and short circuit/ over load on the output. The current limiting element Q1, 303, may be incorporated into the diode bridge 302 using two diodes and two SCR's (Silicon Controlled Rectifiers), reducing the number of forward drops, but increasing the complexity. In general, the diagram for the boost converter is quite simple, but the transformed power is handled by two diodes in the diode bridge 302, the current limiting element Q1 and either the boost switch Q2 or the diode D2, giving four active elements in the current path. Secondly the boost converter 301 is limited to regulate output voltages always above the input voltage including input voltage transients which are not suppressed by the input filter. For some applications a lower output voltage is preferable.

In Fig. 4 is shown the general block diagram of a converter 401 having a non-isolated AC-DC converter 402 having a power factor correction control circuit 403 and being followed by a DC-DC converter 404, while in Fig. 5 is shown a block diagram of a converter 501 having an isolated AC-DC converter 502 having a power factor correction control circuit 503, but without the DC-DC converter of Fig. 4. The converter 501 of Fig. 5 may have a higher ripple in the output when compared to the converter 401 of Fig. 4 due to the lack of the DC-DC converter 404.

From the above discussion it should be clear that switching converters using power factor correction techniques may be widely used, and it is therefore within the objec-

tive of the present invention to provide switching topologies which may also be used in connection with power factor correction.

5 However, the main objective for the new topologies provided by the present invention is to provide a solution without a rectifying diode bridge in the AC input. It is also an objective of the present invention to provide a solution without a current limiting element following the diode bridge.

10 The present invention provides solutions for non-isolated converters, for converters using integrated magnetic components, and for isolated converters, which solutions will be further described in the following.

#### AC-SEPIC

15 In Fig. 6 is shown a prior art DC-DC converter 601 of the SEPIC (Single Ended Primary Inductance Converter) topology, in which a DC voltage  $V_{in}$  is feed into an input inductor L1 602, which are switched between the return path RTN 606 and a coupling capacitor C1 603 by a switch transistor Q1 604. The transistor Q1 604 is switched between on and off states by pulse width modulation via a control input  
20 605. An output inductor L2 607 is arranged between the return path 606 and the output of the coupling capacitor C1 603, and a rectifying diode D1 608 is arranged between the coupling capacitor 603 and an output capacitor C3 609, with the output capacitor 609 having the other terminal connected to the return path 606. A DC voltage output  $V_{out}$  may be supplied via the output capacitor 609 to a load.

25

The SEPIC converter of Fig. 6 may be divided into a primary circuit comprising the input inductor L1 602, the switch Q1 604 and the coupling capacitor C1, 603, and a secondary circuit comprising the output inductor L2 607, the rectifier D1 608 and the output capacitor C3 609.

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An embodiment of an AC-DC converter according to the present invention using a SEPIC topology without a diode bridge in the AC input, which may be referred to as an AC-SEPIC topology, is shown in Fig. 7. The converter of Fig. 7 may also be described as a double SEPIC converter supplied directly from an AC-Source.

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In Fig. 7, the AC input signal is feed into an input inductor L3 being a coupled inductor having a first winding 702a and a second winding 702b. The other end of the first winding 702a is connected to a first terminal of a first power switch Q1 704a and a first terminal of a first coupling capacitor C1 703a, with a second terminal of the switch Q1 704a being connected to a return path 706. The switch Q1 704a has a control terminal 705a for controlling the switch in on and off states. A first output inductor L1 707a is arranged between the return path 706 and a second terminal of the coupling capacitor C1 703a, with the second terminal of the capacitor C1 703a further being connected to an anode input of a first rectifying diode D1 708a. The diode D1 708a has the cathode connected to a first terminal of an output capacitor C3 709, with the other terminal of the output capacitor C3 709 being connected to the return path.

In a similar way, the second winding 702b is connected to a second power switch Q2 704b and a second coupling capacitor C2 703b, with the second terminal of the switch Q2 704b being connected to the return path 706, and with the switch Q2 704b having a control terminal 705b for controlling the switch in on and off states. A second output inductor L2 707b is arranged between the return path 706 and a second terminal of the second coupling capacitor C2 703b, with the second terminal of the capacitor C2 703b further being connected to an anode input of a second rectifying diode D2 708b. The diode D2 708b has the cathode connected to the first terminal of the output capacitor C3 709. A DC voltage output Vout may be supplied via the output capacitor 709 to a load.

The converter of Fig. 7 may also be divided into a primary circuit and a secondary circuit, in which the primary circuit comprises the input inductor L3, the switches Q1 and Q2, and the coupling capacitors C1 and C2, and the primary circuit has an output comprising the return path 706 and a first forward path including the second terminal of C1 and a second forward path including the second terminal of C2. The secondary circuit comprises the output inductors L1 and L2, the diodes D1 and D2 and the output capacitor C3, and the secondary circuit has an input comprising a return path coupled to the return path 706 of the primary circuit, a first forward path connecting the inductor L1 and the diode D1 to the second terminal of C1, and a second forward path connecting the inductor L2 and the diode D2 to the second terminal of C2.

For the embodiment shown in Fig. 7, the switches are N-channel MOSFET transistors, which will conduct as diodes when the second terminals are positive compared to the first terminals.

5

For the circuit of the Fig. 7, the components L3, Q1, C1, L1, D1 and C3 are working as a SEPIC converter, when the AC input voltage to the first winding 702a, Vac+, is positive when compared to the input voltage of the second winding 702b, Vac-.

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During periods of a positive AC input voltage to the first winding, the return path should be connected to the second winding 702b. This could be done by having Q2 controlled to be on when the AC voltage is positive, but when using the N-channel MOSFETs, this is not necessary as Q2 will be conducting as a diode because of the internal body diode.

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Similarly, the components L3, Q2, C2, L2, D2 and C3 are working as a SEPIC converter, when the AC input voltage to the first winding 702a, Vac+ is negative when compared to the input voltage of the second winding 702b, Vac-. For negative AC input voltage to the first winding 702a, the return path should be connected to the first winding 702a. Again, this could be done by having Q1 controlled to be on when the AC voltage is negative, but when using the N-channel MOSFETs, this is not necessary as Q1 will be conducting as a diode because of the internal body diode.

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The fact that Q2 is conducting as a diode for positive input voltages and Q1 is conducting as a diode for negative input voltages gives the possibility for connecting the two control signals together and thereby using a standard single output pulse width modulated, PWM, control circuit for controlling the switches Q1 and Q2. The PWM control circuit should preferably be a standard PFC control circuit. Thus, the switching frequency should be very much higher than the 50 Hz or 60 Hz line frequency of the AC input, such as for example in the range of 50-200 kHz.

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For the embodiment shown in Fig. 7, the input inductor L3 is a coupled inductor with two windings. However, the converter may be operating with two separate inductors 702a and 702b, and the converter may also be operating with only one inductor, in which case the inductor L3 might only have one winding 702a or 702b. When L3 only includes winding 702a, this winding would be connecting the Vac+ input to the

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first coupling capacitor C1 and the first switch Q1, with the Vac- input being coupled to the second capacitor C2 and the switch Q2. Similarly, if L3 only includes winding 702b, the Vac+ should be coupled to the first capacitor C1 and the switch Q1.

5 Waveform diagrams illustrating voltage waveforms occurring in the converter of Fig. 7 are illustrated in Fig. 8a-8c. Fig. 8a shows the voltage across diode D1 for positive input voltages, when the switch Q1 is switched on and off and the switch Q2 is conducting as a diode. The duty cycle is 40%, meaning that the switch Q1 is on 40% and off 60% of a switch period. From Fig. 8a it may be seen that during the on periods, when the capacitor C1 has the first terminal connected to the return path, the diode D1 is reversed biased by a voltage  $V_{ac} + V_{out}$ , where  $V_{ac}$  is the AC input voltage and  $V_{out}$  is the voltage across the output capacitor C3. During the off periods the diode D1 is conducting resulting in the normal diode voltage drop. The voltage across the second diode D2 is the same as shown in Fig. 8a when the AC input voltages are negative.

Fig. 8b illustrates the voltage across switch Q1 for positive AC input voltages when Q2 is conducting as a diode for a duty cycle of 40%. During on periods, the switch Q1 is conducting, while in the off periods, the diode D1 is conducting and the voltage across Q1 equals  $V_{ac} + V_{out}$ . The voltage across the second switch Q2 is the same as shown in Fig. 8b when the AC input voltages are negative.

In Fig. 8c is illustrated the voltage from the Vac+ input to the first terminal of Q1, equal to the drain terminal of Q1, for positive AC input voltages, which is similar to the voltage across the first winding 702a, and equal to half the total voltage across the input inductor L3 including both windings 702a and 702b. Also here, the duty cycle is 40%. The voltage across the second winding 702b equal to the voltage from the drain terminal of Q2 to the Vac- input is the same as shown in Fig. 8c when the AC input voltages are negative.

The change in the current of the input inductor L3 with a switch duty cycle of 40% is illustrated in the waveform diagram of Fig. 9. Here it is seen that the current is increasing during on periods and decreasing during off periods.

Some of the advantages of the double SEPIC topology of Fig. 7 are the same as for the SEPIC converter. Hence, the DC transfer function from input to output in continuous conduction mode is:

5       $V_{out} / |(V_{ac+}) - (V_{ac-})| = D / (1-D),$

where D is the duty cycle (the on time for Q1 divided with the switch period), and  $|(V_{ac+}) - (V_{ac-})|$  is the numerical value of the voltage on the AC input.

10      This gives the opportunity of optimising the output voltage,  $V_{out}$ , for the stage following the AC-DC converter, since the output voltage,  $V_{out}$ , may be chosen to be above or below the input voltage.

15      The double SEPIC topology allows a regulation from zero to nominal output voltage, thereby eliminating the need for a dedicated start-up protection circuit. Even though the topology is non-isolated, the output is protected against over voltage which otherwise may arise from semiconductor component failures. The input current is not chopped, which reduces the need for input filtering.

20      The main advantage in the double SEPIC topology is the ability to operate directly from an AC-Bus. This eliminates the input diode bridge and the associated losses, resulting in only two rectifier losses instead of three, or four when a current limiting element is inserted in the current path from input to output.

25      The disadvantages in the double SEPIC topology are the same as for a SEPIC converter.

30      The current delivered for the output capacitor C3 via the diodes D1 or D2 is chopped and depends on the polarity of the input voltage Vac. A large output capacitor C3 may be required when using power factor correction in order to limit the fundamental ripple from the AC input voltage, thereby minimising the problems from the switching frequency.

35      The coupling capacitors C1 and C2 are placed directly in the path between input and output, whereby all power is handled through these capacitors. The voltage

stress for the capacitors C1 and C2 is the input voltage  $|(V_{ac+}) - (V_{ac-})|$ . The voltage stress for the switches Q1, Q2 and the rectifiers D1, D2 is the input voltage plus the output voltage  $(|(V_{ac+}) - (V_{ac-})| + V_{out})$ . It is noted that the two output stages are in parallel and one stage is active for positive input voltage, and the other is active for negative input voltage.

It is possible to use an integrated magnetic component for all the inductors of the double SEPIC topology of Fig. 7. This is illustrated in Fig. 10, in which a 3 leg core 1001 is used winding an inductor on each leg. Thus, inductor L1 is wound on leg 1, inductor L2 is wound on leg 2 and inductor L3 has its windings 702a and 702b wound on leg 3, thereby creating a magnetic coupling between L1 and L3 for positive input voltages and a magnetic coupling between L2 and L3 for negative input voltages.

The components of the converter shown in Fig. 10 are the same as for the converter of Fig. 7, except for the integrated magnetic component.

One of the main advantages in using integrated magnetic components is a reduced inrush transient during bus plug in. The coupling capacitor charged is C1 or C2 depending of the polarity of the input voltage. The peak current transient is controlled by the value of the capacitors C1 or C2 and the value of the stray inductance between L3 and L1 or L2. This resonance circuit can be damped with either a resistor in parallel with an inductor placed in series with the inductor L3 on the AC input side or with a resistor in series with a capacitor placed in parallel with the capacitor C1 and similar for the capacitor C2. The simplest solution is the inductor solution because of the small value of the stray inductance. An inductor placed in series with L3 will also force the ripple current into L1 and L2, thereby reducing the input ripple current.

An isolated version of the converter topology of Fig. 7 can be achieved by replacing the inductors L1 and L2 with transformers as shown in Fig. 11. Here the output inductor L1 is replaced by a transformer T1, 1107a, and the output inductor L2 is replaced by a transformer T2, 1107b. The remaining components are the same as the components of Fig. 7, but the reference numbers now start with 11 followed by the corresponding two numbers given in Fig. 7. If the converter of Fig. 11 is divided



into a primary and a secondary circuit, transformers T1 and T2 may be regarded as parts of the secondary circuit, with the first and second forward paths of the primary circuit being denoted 1110a and 1110b, the return path of the primary circuit being denoted 1106, and with the first and second forward paths of the secondary circuit being denoted 1111a and 1111b, and the return path of the secondary circuit being denoted 1112.

The isolated solution of Fig. 11 may also use an integrated magnetic component in the same manner as for the non isolated version, having T1 on a first leg, T2 on a second leg and L3 on the third leg of a 3 leg core.

#### AC-CUK

In Fig. 12 is shown a prior art DC-DC converter 1201 of the CUK topology, in which a DC voltage  $V_{in}$  is feed into an input inductor L1 1202, which are switched between the return path RTN 1206 and a coupling capacitor C1 1203 by a switch transistor Q1 1204. The transistor Q1 1204 is switched between on and off states by pulse width modulation via a control input 1205. A rectifying diode D1 1208 is arranged between the return path 1206 and the output of the coupling capacitor C1 1203, and an output inductor L2 1207 is arranged between the coupling capacitor 1203 and an output capacitor C3 1209, with the output capacitor 1209 having the other terminal connected to the return path 1206. A DC voltage output  $V_{out}$  may be supplied via the output capacitor 1209 to a load.

The CUK converter of Fig. 12 may be divided into a primary circuit comprising the input inductor L1 1202, the switch Q1 1204 and the coupling capacitor C1, 1203, and a secondary circuit comprising the output inductor L2 1207, the rectifier D1 1208 and the output capacitor C3 1209.

An embodiment of an AC-DC converter 1301 according to the present invention using a CUK topology without a diode bridge in the AC input, which may be referred to as an AC-CUK topology, is shown in Fig. 13. The converter of Fig. 13 may also be described as a double CUK converter supplied directly from an AC-Source.

In Fig. 13, the AC input signal is feed into an input inductor L3 being a coupled inductor having a first winding 1302a and a second winding 1302b. The other end of the first winding 1302a is connected to a first terminal of a first power switch Q1 1304a and a first terminal of a first coupling capacitor C1 1303a, with a second terminal of the switch Q1 1304a being connected to a return path 1306. The switch Q1 1304a has a control terminal 1305a for controlling the switch in on and off states. A first rectifying diode D1 1308a has the cathode connected to the return path 1306 and the anode connected to the second terminal of the capacitor C1 1303a and one end of a first output inductor L1 1307a. The other end of the inductor L1 1307a is connected to a first terminal of an output capacitor C3 1309 with the other terminal of the output capacitor C3 1309 being connected to the return path.

In a similar way, the second winding 1302b is connected to a second power switch Q2 1304b and a second coupling capacitor C2 1303b, with the second terminal of the switch Q2 1304b being connected to the return path 1306, and with the switch Q2 1304b having a control terminal 1305b for controlling the switch in on and off states.

A second rectifying diode D2 1308b has the cathode connected to the return path 1306 and the anode connected to the second terminal of the capacitor C2 1303b and one end of a second output inductor L2 1307b. The other end of the inductor L2 1307b is connected to the first terminal of the output capacitor C3 1309. A DC voltage output  $V_{out}$  may be supplied via the output capacitor 1309 to a load.

The converter of Fig. 13 may also be divided into a primary circuit and a secondary circuit, in which the primary circuit comprises the input inductor L3, the switches Q1 and Q2, and the coupling capacitors C1 and C2, and the primary circuit has an output comprising the return path 1306 and a first forward path including the second terminal of C1 and a second forward path including the second terminal of C2. The secondary circuit comprises the output inductors L1 and L2, the diodes D1 and D2 and the output capacitor C3, and the secondary circuit has an input comprising a return path coupled to the return path 1306 of the primary circuit, a first forward path connecting the inductor L1 and the diode D1 to the second terminal of C1, and a second forward path connecting the inductor L2 and the diode D2 to the second terminal of C2.

For the embodiment shown in Fig. 13, the switches are also N-channel MOSFET transistors, which will conduct as diodes when the second terminals are positive compared to the first terminals.

5

For the circuit of the Fig. 13, the components L3, Q1, C1, L1, D1 and C3 are operating as a CUK converter, when the AC input voltage to the first winding 1302a, Vac+, is positive when compared to the input voltage of the second winding 1302b, Vac-. During periods of a positive AC input voltage to the first winding, the return  
10 path should be connected to the second winding 1302b. As already discussed, this could be done by having Q2 controlled to be on when the AC voltage is positive, but when using the N-channel MOSFETs, this is not necessary as Q2 will be conducting as a diode because of the internal body diode.

15 Similarly, the components L3, Q2, C2, L2, D2 and C3 of Fig. 13 are operating as a CUK converter, when the AC input voltage to the first winding 1302a, Vac+ is negative when compared to the input voltage of the second winding 1302b, Vac-. For negative AC input voltage to the first winding 1302a, the return path should be connected to the first winding 1302a. Again, this could be done by having Q1 controlled  
20 to be on when the AC voltage is negative, but when using the N-channel MOSFETs, this is not necessary as Q1 will be conducting as a diode because of the internal body diode.

It should be clear that the primary circuit of the converter of Fig. 13 is similar to the  
25 primary circuit of the converter of Fig. 7, so also for the converter of Fig. 13 the two control signals for the switches Q1 and Q2 may be connected together making it possible to use a standard single output pulse width modulated, PWM, control circuit for controlling the switches Q1 and Q2. Also here, the PWM control circuit should preferably be a standard PFC control circuit, and the switching frequency should be  
30 very much higher than the 50 Hz or 60 Hz line frequency of the AC input, such as for example in the range of 50-200 kHz.

Also for the converter of Fig. 13, the input inductor L3 is a coupled inductor with two windings, but again, the converter may be operating with two separate inductors  
35 1302a and 1302b, and the converter may also be operating with only one inductor,

in which case the inductor L3 might only have one winding 1302a or 1302b, see also the description of the converter of Fig. 7.

5 The waveform diagrams of Fig. 8a-8c also illustrate voltage waveforms occurring in the converter of Fig. 13, where Fig. 8a shows the voltage across diode D1 for positive input voltages, when the switch Q1 is switched on and off and the switch Q2 is conducting as a diode. The voltage across the second diode D2 is the same as shown in Fig. 8a when the AC input voltages are negative. Fig. 8b illustrates the voltage across switch Q1 for positive AC input voltages when Q2 is conducting as a diode. The voltage across the second switch Q2 is the same as shown in Fig. 8b 10 when the AC input voltages are negative. In Fig. 8c is illustrated the voltage from the Vac+ input to the first terminal of Q1, equal to the drain terminal of Q1, for positive AC input voltages. The voltage from the drain terminal of Q2 to the Vac- input is the same as shown in Fig. 8c when the AC input voltages are negative.

15 The change in the current of the input inductor L3 of the converter of Fig. 13 is also illustrated in the waveform diagram of Fig. 9.

20 Some of the advantages of the double CUK topology of Fig. 13 are the same as for the CUK converter. Hence, the DC transfer function from input to output in continuous conduction mode is:

$$V_{out} / [(V_{ac+}) - (V_{ac-})] = -D / (1-D),$$

25 which is the same as for the converter of Fig. 7 except that the output voltage has changed sign, and the discussion applied to the advantages of the converter of Fig. 7 may also be applied to the converter of Fig. 13.

30 The disadvantages in the double CUK topology are the same as for a CUK converter. The output voltage is negative, which eliminates the possibility of the same ground reference for a PFC control circuit and a following DC-DC converter. Also here, the coupling capacitors C1 and C2 are placed directly in the path between input and output, whereby all power is handled through these capacitors. The voltage stress for the capacitors C1 and C2 is the input voltage  $|(V_{ac+}) - (V_{ac-}) + V_{out}|$ . 35 The voltage stress for the switches Q1, Q2 and the rectifiers D1, D2 is the input

voltage plus the output voltage ( $|(\text{Vac}+) - (\text{Vac}-)| + \text{Vout}$ ). It is noted that the two output stages are in parallel and one stage is active for positive input voltage, and the other is active for negative input voltage.

5 Also here is it possible to use an integrated magnetic component for all the inductors. This is illustrated in Fig. 14, in which a three leg core 1401 is used having and inductor wound on each leg. Thus, inductor L1 is wound on leg 1, inductor L2 is wound on leg 2 and inductor L3 has its windings 1302a and 1302b wound on leg 3, thereby creating a magnetic coupling between L1 and L3 for positive input voltages  
10 and a magnetic coupling between L2 and L3 for negative input voltages.

The components of the converter shown in Fig. 14 are the same as for the converter of Fig. 13, except for the integrated magnetic component. The discussion concerning the magnetic circuit of Fig. 10 also covers the magnetic circuit of Fig. 14.

15 Fig. 15 shows a transformer isolated version of the AC-DC converter of Fig. 13. Here, the coupling capacitors C1 and C2 are both divided in two, so that the circuit further comprises two coupling capacitors C5 and C4, 1513a and 1513b. Furthermore, a first transformer T1, 1514a, and a second transformer T2, 1514b, are introduced. The remaining components are similar to the components of Fig. 13, but the reference numbers now start with 15 followed by the corresponding two numbers given in Fig. 13. If the converter of Fig. 15 is divided into a primary and a secondary circuit, the first and second forward paths of the primary circuit is denoted 1510a and 1510b, the return path of the primary circuit being denoted 1506, and with the  
20 the first and second forward paths of the secondary circuit being denoted 1511a and 1511b, and the return path of the secondary circuit being denoted 1512.

The primary circuit of Fig. 15 is similar to the primary circuit of Fig. 13, but in the secondary circuit, the transformer T1 has one end of a primary winding connected to the first forward path 1511a of the secondary circuit, and via the first forward path of the primary circuit 1510a to the capacitor C1. The other end of the primary winding of T1 is connected to the return path 1512, which again is connected to the return path 1506. In the same way, the transformer T2 has one end of a primary winding connected to the second forward path 1511b of the secondary circuit, and via the second forward path of the primary circuit 1510b to the capacitor C2. The other end  
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of the primary winding of T2 is connected to the return path 1512, which again is connected to the return path 1506.

5 The secondary winding of T1 has one end connected to a first terminal of the capacitor C5, which has a second terminal connected to the inductor L1 and the anode of the diode D1. The other end of the secondary winding of T1 is connected to the anode side of diode D1 and the second terminal of the output capacitor C3. In the same way, the secondary winding of T2 has one end connected to a first terminal of the capacitor C4, which has a second terminal connected to the inductor L2 and the anode of the diode D2. The other end of the secondary winding of T2 is connected to the anode side of diode D2 and the second terminal of the output capacitor C3. As in Fig. 13, the other ends of the inductors L1 and L2 are connected to the first terminal of the capacitor C3.

10 15 The isolated solution of Fig. 15 may also use an integrated magnetic component in the same manner as for the non isolated version, having T1 on a first leg, T2 on a second leg and L3 on the third leg of a 3 leg core.

#### AC-HYBRIDGE

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Fig. 16 shows an embodiment of an AC-DC converter according to the present invention using a Hybridge topology without a diode bridge in the AC input, which may be referred to as an AC-HYBRIDGE.

25 In Fig. 16 the AC signal is feed into an input inductor L3 being a coupled inductor having a first winding 1602a and a second winding 1602b. The other end of the first winding 1602a is connected to a first terminal of a first power switch Q1 1604a and a first terminal of a first coupling capacitor C1 1603a, with a second terminal of the switch Q1 1604a being connected to a return path 1606. The switch Q1 1604a has a control terminal 1605a for controlling the switch in on and off states. The capacitor C1 has the second terminal connected to a first terminal of a switch Q3 1611a and one end of the primary winding of a transformer T1 1610. A second terminal of the switch Q3 1611a is connected to the return path 1606. The switch Q3 1611a has a control terminal 1612a for controlling the switch in on and off states.

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In a similar way, the second winding 1602b is connected to a second power switch Q2 1604b and a second coupling capacitor C2 1603b, with the second terminal of the switch Q2 1604b being connected to the return path 1606, and with the switch Q2 1604b having a control terminal 1605b for controlling the switch in on and off states. The capacitor C2 1606b has the second terminal connected to a first terminal of a switch Q4 1611b and the other end of the primary winding of transformer T1. A second terminal of the switch Q4 1611b is connected to the return path 1606. The switch Q4 1611b has a control terminal 1612b for controlling the switch in on and off states.

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The transformer T1 1610 has one end of the secondary winding connected the anode of a diode D1 1608a and one end of a first output inductor L1 1607a. The cathode of the diode D1 is connected to a first terminal of an output capacitor C3 1609 with the other terminal of the output capacitor C3 1609 being connected to the other end of the inductor L1. The other end of the secondary winding of T1 1610 is connected to the anode of a diode D2 1608b and one end of a second output inductor L2 1607b. The cathode of the diode D2 is connected to the first terminal of the capacitor C3 1609 with the other terminal of the output capacitor C3 1609 being connected to the other end of the inductor L2. A DC voltage output Vout may be supplied via the output capacitor 1609 to a load.

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For the embodiment shown in Fig. 16, the switches Q1 and Q2 are also N-channel MOSFET transistors where the first terminal is the drain terminal, the second terminal is the source terminal and the control terminal is the gate terminal. These N-channel MOSFET transistors will conduct as diodes when the second terminals are positive compared to the first terminals. However, for the switches Q3 and Q4 it is preferred to use P-channel MOSFET transistors where the first terminal is the drain terminal, the second terminal is the source terminal and the control terminal is the gate terminal. These P-channel MOSFET transistors will conduct as diodes when the first terminals are positive compared to the second terminals.

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The functionality of the AC-HYBRIDGE converter as illustrated in Fig. 16 is described in the following for a positive Vac:

The switch Q1 is controlled with a duty cycle D from a control circuit. The switch Q2 is constant on or can be controlled by D if the switch is a MOSFET or if there is a diode parallel with the switch. The inductor L3 is used in the same manner as a boost inductor, with the same waveforms. This gives the same waveforms on the switch Q1 as for a boost switch.

For positive input voltage Q3 is conducting when Q1 is in an off period, which is in the period (1-D), while Q4 is constant off for positive input voltage. The state of the switches Q3 and Q4 changes when the input voltage is negative. Thus, Q3 is constant off and Q4 is conducting when Q2 is in an off period, which is in the period (1-D).

The voltage on the capacitor C1 is clamped by the switch Q3 and the switch Q2, giving the boost voltage across the capacitor C1. The voltage across the capacitor C2 is set by the input voltage Vac and the voltage across the capacitor C1, because the voltage across the inductor L3 and the transformer T1 may be set to zero when DC wise. The voltage on the transformer T1 will be the same as for the inductor L1, whereby the voltage is -Vac for Q1 on and  $Vac \cdot D / (1-D)$  for Q1 off.

The voltage across the diode D1 will be the reflected voltage from the transformer T1, when the switch Q1 is on. The voltage across the diode D2 will be the reflected voltage from the transformer T1, when the switch Q1 is off. The current in inductors L1 and L2 will be controlled by the balancing of the capacitors C1 and C2 on the primary side.

When the input voltage Vac changes polarity the following components will swap functionality: Q1 – Q2, C1 – C2, Q3 – Q4, L1 – L2 and D1 – D2.

The DC transfer function from input to output in continuous conduction mode is:

$$V_{out} / [(V_{ac+}) - (V_{ac-})] = D \cdot N,$$

where D is the duty cycle and N is the turn ratio on T1, that is the number of turns of the secondary winding divided by the number of turns of the primary winding.



For positive  $V_{ac}$ , that is when  $(V_{ac+}) - (V_{ac-})$  is positive, and continuous conduction mode approximate voltages of components of Fig. 16 are given in the following:

voltage across C1:  $V_{ac}/(1-D)$ ,

5 voltage across C2:  $-V_{ac} \cdot D/(1-D)$ ,

0

voltage across Q1:  $V_{ac}/(1-D)$ ,

voltage across Q2: 0,

10 voltage across Q3:  $V_{ac}/(1-D)$ ,

voltage across Q4:  $V_{ac} \cdot D/(1-D)$ ,

voltage across D1:  $V_{ac}/N$ , and

voltage across D2:  $V_{ac} \cdot D/(N \cdot (1-D))$ .

15

Waveform diagrams illustrating voltage waveforms occurring in the converter of Fig. 16 are illustrated in Fig. 17a-17c. Fig. 17a shows the voltage across switches Q3 and Q4 for positive input voltages and a duty cycle of 40%. It may be seen that during the on periods, the switch Q3 is reversed biased by a voltage  $V_{ac}/(1-D)$ , while Q3 is conducting in the off periods. When the AC input voltage is positive, switch Q4 is constantly reversed biased by a voltage  $V_{ac} \cdot D/(1-D)$ . The voltage across Q3 and Q4 will be swapped for negative AC input voltages.

20

Fig. 17b illustrates the voltage across switch Q1 for positive AC input voltages when Q2 is conducting as a diode for a duty cycle of 40%. During on periods, the switch Q1 is conducting, while in the off periods the voltage across Q1 equals  $V_{ac}/(1-D)$ . The voltage across the second switch Q2 is the same as shown in Fig. 17b when the AC input voltages are negative.

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In Fig. 17c is illustrated the voltage from the  $V_{ac+}$  input to the first terminal of Q1, equal to the drain terminal of Q1, for positive AC input voltages. Also here, the duty cycle is 40%. The inductor L3 has two windings 1602a and 1602b, and during the on periods, the voltage is  $V_{ac}/2$  and during the off periods the voltage is  $-V_{ac} \cdot D/(2(1-D))$ . The voltage from the drain terminal of Q2 to the  $V_{ac-}$  input is the same as shown in Fig. 17c when the AC input voltages are negative.

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The main advantage of the AC-HYBRIDGE topology is again the ability to operate directly from an AC-Bus, which eliminates the input diode bridge and the associated losses, giving only two rectifiers losses instead of three, or four when a current limit-  
 5 ing element is in the current path from input to output. Compared to the AC-SEPIC and the AC-CUK, both the output stages of the AC-HYBRIDGE are active for all polarities of the input voltage.

The disadvantages of the AC-HYBRIDGE topology are substantially the same as for  
 10 the above discussed AC-SEPIC and AC-CUK topologies. The voltage stress for capacitors C1 and C2 is  $(|V_{ac+}| - V_{ac-})/(1-D)$ , which is higher than the input voltage. The voltage stress for the switches Q1, Q2, Q3 and Q4 is also  $(|V_{ac+}| - V_{ac-})/(1-D)$ , which again is higher than the input voltage.

Also for the AC-HYBRIDGE converter is it possible to use an integrated magnetic  
 15 component for the inductors. This can be done by using a 3 leg core having an inductor wound on each leg, with L1 1607a wound on leg 1, L2 1607b wound on leg 2 and the transformer T1 1620 wound on leg 3, thereby creating a magnetic coupling between L1, L2 and T1. Furthermore, the input inductor L3 has the same voltage  
 20 waveform as T1 creating the possibility of placing T1 and L3 on the same leg 3 of the integrated magnetic component.

The different topologies of the AC-DC converter of the present invention may com-  
 25 prise a primary circuit, which may have the components as shown in the circuit of in Fig. 18. Here, the AC signal is feed into an input inductor L3, which may be a coupled inductor having a first winding 1802a and a second winding 1802b. However, as already discussed, the inductor L3 need no be a coupled inductor, and L3 may only have one winding, either 1802a or 1802b. In Fig. 18, the other end of the first winding 1802a is connected to a first terminal of a first power switch Q1 1804a and a  
 30 first terminal of a first coupling capacitor C1 1803a, with a second terminal of the switch Q1 1804a being connected to a return path 1806. The switch Q1 1804a has a control terminal 1805a for controlling the switch in on and off states. The capacitor C1 has the second terminal being connected to a first forward path of the primary circuit. In the same way, the other end of the second winding 1802b is connected to  
 35 a first terminal of a second power switch Q2 1804b and a first terminal of a second

coupling capacitor C2 1803b, with a second terminal of the switch Q2 1804b being connected to a return path 1806. The switch Q2 1804a has a control terminal 1805b for controlling the switch in on and off states. The capacitor C2 has the second terminal being connected to a second forward path of the primary circuit.

5

The primary circuit part of Fig. 18 is also controlled in the same manner for the different topologies, even though the input to output DC transfer functions may be different. For a positive input voltage Vac ((Vac+) – (Vac-)), Q1 is working as the controlling switch with the duty cycle D. On the other hand, Q2 may be constant on for a positive input voltage Vac. This can be realised by having two control signals as shown in Fig. 18 (control 1 and control 2), or by using for example N – channel MOSFETS for the switches. As already mentioned, this can simplify the control circuitry to comprise only one control signal driving both switches Q1 and Q2. To have the same simplified control, a discrete diode can be arranged for each switch, when using other types of switches, said diode providing a current path from the return path 1806 and the corresponding winding of the inductor L3. The simplified control with one control signal can be a big advantage, because most power factor controllers have only one output control pin.

## 20 EXPERIMENTAL RESULTS

To demonstrate the high performance of the AC-DC converter of the present invention, a model of the AC-SEPIC with integrated magnetic components (see Fig. 10) was designed, using the following data and components:

25

Input voltage:	100Vac – 260Vac
Output voltage:	180Vdc
Output power:	Up to 500W

30

C1, C2:	3.3uF, 630V
Q1, Q2:	SPP20N60C2
D1, D2:	STTH806 from STM (S.T. Microelectronics)
C3:	2000uF, 250V (2 pcs 1000uF)

L1, L2 and L3: L3 was wound on the centre leg on an E55/28/21 core, L1 and L2 were wound on the side legs. The number of turns is 56 and the inductance is 210 $\mu$ H. There are common air gaps in all three legs.

- 5 The control terminals of switches Q1 and Q2 were connected together being controlled by a control signal with a switching frequency of 100 kHz. The control signal was a pulse width modulated, PWM, signal being the output of a power factor correction, PFC, circuit designed to give a power factor of 0.99 at full load.
- 10 For the above example, the input current waveforms for an input voltage of  $V_{in}$  equal to 134Vrms, a power factor, PF, equal to 0.99, and an output power,  $P_{out}$ , of 134W are plotted in Fig. 19. Here, the y-axis shows 1A/Div and the x-axis shows 5ms/Div. The voltage waveforms of the power switches Q1 and Q2 for the same  $V_{in}$ , PF and  $P_{out}$  as in Fig. 19 are plotted in Fig. 20. In Fig. 20, the drain-source
- 15 voltage for Q1 is shown at the top of the figure, while the drain-source voltage for Q2 is shown at the bottom of the figure with the y-axis showing 200V/Div and the x-axis showing 5ms/Div. In Fig. 21 the drain-source voltage of switch Q2, top of figure, is compared to the voltage across the output diode D2, bottom of figure, with the y-axis showing 200V/Div and the x-axis showing 5ms/Div. The output voltage ripple for an
- 20 input voltage  $V_{in}$  of 191Vrms, PF equal to 0.99, and an output power,  $P_{out}$ , of 460W is plotted in Fig. 22, where the y-axis shows 1V/Div and the x-axis shows 2ms/Div.

While the invention has been particularly shown and described with reference to particular embodiments, it will be understood by those skilled in the art that various

25 changes in form and details may be made therein without departing from the spirit and scope of the invention, and it is intended that such changes come within the scope of the following claims.

## CLAIMS

1. An AC-DC power converter having no input rectifiers, said power converter comprising:

5

a primary circuit for coupling to an AC voltage source via a first AC input and a second AC input, and with an output having a first forward path, a second forward path and a return path, and

10

a secondary circuit with an input having a first forward path, a second forward path and a return path for receiving power via the corresponding output paths of the primary circuit, and with first and second outputs for delivering a DC power to a load,

wherein said primary circuit comprises:

15

a first current path between the first AC input and a first output end, a second current path between the second AC input and a second output end, a first power switch, a second power switch, a first coupling capacitor with first and second terminals, a second coupling capacitor with first and second terminals, a first input inductor being arranged in the first current path between the first AC input and the first output end and/or a second input inductor being arranged in the second current path between the second AC input and the second output end,

20

means for providing a current path from the return path to the second output end during at least part of a period of positive AC input voltage, during which period the input voltage at the first AC input is positive compared to the voltage of the second AC input, and

25

means for providing a current path from the return path to the first output end during at least part of a period of negative AC input voltage, during which period the input voltage at the first AC input is negative compared to the voltage of the second AC input,

30

said first power switch and said first coupling capacitor being arranged so that when the first switch is on, a current can flow from the first AC input, via the first current path, through the first switch and into the return path, and so that when the first switch is off, a current can flow from the first AC input, through the first current path

35

and into the first coupling capacitor via the first terminal of the first coupling capacitor, said first coupling capacitor being arranged so that a current can flow from its second terminal, via the first forward path of the primary circuit and into the first forward path of the secondary circuit, and

5

said second power switch and said second coupling capacitor being arranged so that when the second switch is on, a current can flow from the second AC input, via the second current path, through the second switch and into the return path, and so that when the second switch is off, a current can flow from the second AC input, through the second current path and into the second coupling capacitor via the first terminal of the second coupling capacitor, said second coupling capacitor being arranged so that a current can flow from its second terminal, via the second forward path of the primary circuit and into the second forward path of the secondary circuit.

10

2. An AC-DC power converter according to claim 1, wherein the first power switch has a first terminal, a second terminal and a control terminal, and the second power switch has a first terminal, a second terminal and a control terminal, said first output end being coupled to the first terminal of the first switch and the first terminal of the first coupling capacitor, the second terminal of the first switch being coupled to the return path, and the control terminal of the first switch being coupled to means for controlling the first power switch in the on and off states, and said second output end being coupled to the first terminal of the second switch and the first terminal of the second coupling capacitor, the second terminal of the second switch being coupled to the return path, and the control terminal of the second switch being coupled to means for controlling the second power switch in the on and off states.

20

25

3. An AC-DC power converter having no input rectifiers, said power converter comprising:

30

a primary circuit for coupling to an AC voltage source via a first AC input and a second AC input, and with an output having a first forward path, a second forward path and a return path, and

a secondary circuit with an input having a first forward path, a second forward path and a return path for receiving power via the corresponding output paths of the primary circuit, and with first and second outputs for delivering a DC power to a load,

5 wherein said primary circuit comprises:

a first current path between the first AC input and a first output end, a second current path between the second AC input and a second output end, a first power switch with a first terminal, a second terminal and a control terminal, a second power  
10 switch with a first terminal, a second terminal and a control terminal, a first coupling capacitor with first and second terminals, a second coupling capacitor with first and second terminals, a first input inductor being arranged in the first current path between the first AC input and the first output end and/or a second input inductor being arranged in the second current path between the second AC input and the second  
15 output end,

means for providing a current path from the return path to the second output end during at least part of a period of positive AC input voltage, during which period the input voltage at the first AC input is positive compared to the voltage of the second  
20 AC input, and

means for providing a current path from the return path to the first output end during at least part of a period of negative AC input voltage, during which period the input voltage at the first AC input is negative compared to the voltage of the second AC  
25 input,

said first output end being coupled to the first terminal of the first switch and the first terminal of the first coupling capacitor, the second terminal of the first switch being coupled to the return path of the primary circuit, the control terminal of the first switch being coupled to control means for controlling the first switch in on and off  
30 states for conducting current between the first and second terminals of the first switch, the second terminal of the first coupling capacitor being coupled to the first forward path of the primary circuit, and

said second output end being coupled to the first terminal of the second switch and  
35 the first terminal of the second coupling capacitor, the second terminal of the second

switch being coupled to the return path of the primary circuit, and the control terminal of the second switch being coupled to control means for controlling the second switch in on and off states for conducting current between the first and second terminals of the second switch, the second terminal of the second coupling capacitor being coupled to the second forward path of the primary circuit.

4. An AC-DC power converter according to any of the preceding claims, wherein electrical power can be transferred from the primary circuit to the secondary circuit via coupling capacitors only, said power transferring coupling capacitors including the first and second coupling capacitors.

5. An AC-DC power converter according to any of the claims 1-4, wherein electrical power can be transferred from the primary circuit to the secondary circuit via the first and second coupling capacitors only.

6. An AC-DC power converter according to any of the claims 1-4, wherein one or more primary coupling capacitors are electrically coupled in parallel to the first coupling capacitor, and/or one or more secondary coupling capacitors are electrically coupled in parallel to the second coupling capacitor.

7. An AC-DC power converter according to any of the claims 1-4 or 6, wherein one or more primary coupling capacitors have their first and second terminals electrically coupled to the first and second terminals, respectively, of the first coupling capacitor, and/or one or more secondary coupling capacitors have their first and second terminals electrically coupled to the first and second terminals, respectively, of the second coupling capacitor.

8. An AC-DC power converter according to claim 6 or 7, wherein electrical power can be transferred from the primary circuit to the secondary circuit only via the first and second coupling capacitors and said primary and/or secondary coupling capacitors.

9. An AC-DC power converter according to any of the preceding claims, further comprising means for controlling the first and second power switches so that the first power switch is turned on and off a plurality of times during each period of a positive



AC input voltage, and so that the second power switch is turned on and off a plurality of times during each period of a negative AC input voltage.

5 10. An AC-DC power converter according to any of the claims 2-9, wherein each power switch is a N-channel MOSFET transistor having a drain terminal as the first terminal, a source terminal as the second terminal and a gate terminal as the control terminal.

10 11. An AC-DC power converter according to any of the preceding claims, further comprising means for controlling the first and second power switches so that the second power switch is turned on during periods of a positive AC input voltage thereby providing a current path from the return path of the primary circuit to the second output end of the second current path, and so that the first power switch is turned on during periods of negative AC input voltage, thereby providing a current  
15 path from the return path of the primary circuit to the first output end of the first current path.

20 12. An AC-DC power converter according to claim 10, wherein the control terminals of the first switch and the second switch are controlled by a single output signal from the means for controlling the first and second power switches, whereby the second switch is conducting as a rectifying diode for periods of positive AC input voltage when the second switch is off thereby providing a current path from the return path to the second output end,  
25 and the first switch is conducting as a rectifying diode for periods of negative AC input voltage when the first switch is off thereby providing a current path from the return path to the first output end.

30 13. An AC-DC power converter according to any of the claims 1-11, wherein a first input rectifier has an output coupled to the first output end and to the first terminal of the first coupling capacitor and has an input coupled to the return path of the primary circuit, and a second input rectifier has an output coupled to the second output end and to the second terminal of the second coupling capacitor and has an input coupled to the return path of the primary circuit, whereby the first rectifier provides a current path from the return path to the first output end during periods of positive AC

input voltage, and the second rectifier provides a current path from the return path to the second output end during periods of negative AC input voltage.

5 14. An AC-DC power converter according to any of the claims 9-13, wherein the means for controlling the first and second power switches between on and off is adapted to use pulse width modulation.

10 15. An AC-DC power converter according to claim 14, wherein the means for controlling the first and second power switches between on and off is adapted to control the power switches for power factor correction, whereby the input current received from the AC input voltage source is controlled to substantially follow a sine wave.

15 16. An AC-DC power converter according to any of the preceding claims, said converter having both a first input inductor and a second input inductor.

17. An AC-DC power converter according to claim 16, wherein the first and second input inductors are magnetically coupled.

20 18. An AC-DC power converter according to claim 16 or 17, wherein the first input inductor has a first terminal and a second terminal and the second input inductor has a first terminal and a second terminal, the first terminal of the first inductor being coupled to the first AC input and the second terminal of the first inductor being coupled to the first output end, the second terminal of the second inductor being coupled to the second AC input and the first terminal of the second inductor being coupled to the second output end.

30 19. An AC-DC power converter according to claim 16 or 17, wherein the first input inductor has a first terminal and a second terminal and the second input inductor has a first terminal and a second terminal, the second terminal of the first inductor being coupled to the first AC input and the first terminal of the first inductor being coupled to the first output end, the first terminal of the second inductor being coupled to the second AC input and the second terminal of the second inductor being coupled to the second output end.

20. An AC-DC power converter according to any of the preceding claims, wherein said secondary circuit comprises:

5 an output capacitor having a first positive terminal coupled to the first output and a second negative terminal coupled to the second output,

10 a first output rectifier and a first output inductor coupled in series between the first and the second terminals of the output capacitor for transferring power received via the first forward path to the output capacitor, and

a second output rectifier and a second output inductor coupled in series between the first and the second terminals of the output capacitor for transferring power received via the second forward path to the output capacitor.

15 21. An AC-DC power converter according to claim 20, wherein the first and the second output rectifiers have current output ends coupled to the first positive terminal of the output capacitor, and the output inductors are coupled to the second negative terminal of the output capacitor.

20 22. An AC-DC power converter according to claim 20 or 21, wherein

25 the first forward path of the secondary circuit is coupled to an input end of the first output rectifier and one end of the first output inductor, said first output rectifier having an output end coupled to the first terminal of the output capacitor and said first output inductor having the other end coupled to the second terminal of the output capacitor and the return path of the secondary circuit, and wherein

30 the second forward path of the secondary circuit is coupled to an input end of the second output rectifier and one end of the second output inductor, said second output rectifier having an output end coupled to the first terminal of the output capacitor and said second output inductor having the other end coupled to the second terminal of the output capacitor and the return path of the secondary circuit.

35 23. An AC-DC power converter according to claim 20 or 21, wherein

the first forward path of the secondary circuit is coupled to an input end of the first output rectifier and one end of the first output inductor, said first output inductor having the other end coupled to the second terminal of the output capacitor and said first output rectifier having an output end coupled to the first terminal of the output capacitor and the return path of the secondary circuit, and wherein

the second forward path of the secondary circuit is coupled to an input end of the second output rectifier and one end of the second output inductor, said second output inductor having the other end coupled to the second terminal of the output capacitor and said second output rectifier having an output end coupled to the first terminal of the output capacitor and the return path of the secondary circuit.

24. An AC-DC power converter according to claim 22 or 23, wherein the first input and output inductors are magnetically coupled to each other and the second input and output inductors are magnetically coupled to each other.

25. An AC-DC power converter according to claim 24, wherein one or more integrated magnetic components are used for obtaining said magnetic coupling.

26. An AC-DC power converter according to claim 20 or 21, wherein the secondary circuit further comprises a first transformer having a primary winding and a secondary winding, and a second transformer having a primary winding and a secondary winding, said primary winding of the first transformer having one end coupled to the first forward path of the secondary circuit and the other end coupled to the return path of the secondary circuit, said primary winding of the second transformer having one end coupled to the second forward path of the secondary circuit and the other end coupled to the return path of the secondary circuit.

27. An AC-DC power converter according to claim 26, wherein each transformer winding has a first terminal and a second terminal, said terminals of the first primary windings being arranged so that when the first terminal of the primary winding of the first transformer is coupled to the return path, the second terminal of the primary winding of the second transformer is coupled to the return path, or so that when the second terminal of the primary winding of the first transformer is coupled to the re-

turn path, the first terminal of the primary winding of the second transformer is coupled to the return path.

5 28. An AC-DC power converter according to claim 26 or 27, wherein the secondary winding of the first transformer forms the first output inductor, and the secondary winding of the second transformer forms the second output inductor.

29. An AC-DC power converter according to claim 26 or 27, wherein the secondary circuit further comprises a third coupling capacitor with first and second terminals  
10 and a fourth coupling capacitor with first and second terminals,

said secondary winding of the first transformer having one end coupled to the first terminal of the third coupling capacitor and the other end coupled to the first terminal of the output capacitor,  
15

said secondary winding of the second transformer having one end coupled to the first terminal of the fourth coupling capacitor and the other end coupled to the first terminal of the output capacitor,

20 said second terminal of the third coupling capacitor being coupled to an input end of the first output rectifier and one end of the first output inductor, said first output inductor having the other end coupled to the second terminal of the output capacitor, and said first output rectifier having an output end coupled to the first terminal of the output capacitor, and

25 said second terminal of the fourth coupling capacitor being coupled to an input end of the second output rectifier and one end of the second output inductor, said second output inductor having the other end coupled to the second terminal of the output capacitor, and said second output rectifier having an output end coupled to the  
30 first terminal of the output capacitor.

30. An AC-DC power converter according to claim 20 or 21, wherein the secondary circuit further comprises a third transformer having a primary winding and a secondary winding, a third power switch with a first terminal, a second terminal and a con-

trol terminal, and a fourth power switch with a first terminal, a second terminal and a control terminal,

5       said primary winding of the third transformer having one end coupled to the first forward path of the secondary circuit and the other end coupled to the second forward path of the secondary circuit,

10       said third power switch having the first terminal coupled to the first forward path of the secondary circuit, the second terminal coupled to the return path of the secondary circuit, and the control terminal coupled to means for controlling the third power switch in on and off states,

15       said fourth power switch having the first terminal coupled to the second forward path of the secondary circuit, the second terminal coupled to the return path of the secondary circuit, and the control terminal coupled to means for controlling the fourth power switch in on and off states,

20       said secondary winding of the third transformer having one end coupled to an input end of the first output rectifier and one end of the first output inductor, said first output rectifier having an output end coupled to the first terminal of the output capacitor and said first output inductor having the other end coupled to the second terminal of the output capacitor, and

25       said secondary winding of the third transformer having the other end coupled to an input end of the second output rectifier and one end of the second output inductor, said second output rectifier having an output end coupled to the first terminal of the output capacitor and said second output inductor having the other end coupled to the second terminal of the output capacitor.

30       31. An AC-DC power converter according to claim 30, wherein each of the third and fourth power switches is a P-channel MOSFET transistor having a drain terminal as the first terminal, a source terminal as the second terminal and a gate terminal as the control terminal.

32. An AC-DC power converter according to claim 30 or 31, further comprising means for controlling the third and fourth power switches so that the third power switch is turned on and off a plurality of times during each period of a positive AC input voltage, and so that the fourth power switch is turned on and off a plurality of times during each period of a negative AC input voltage.

33. An AC-DC power converter according to any of the claims 30-32, further comprising means for controlling the third and fourth power switches so that for a positive input voltage the fourth power switch is constant off and the third power switch is conducting when the first power switch is in an off period, and so that for a negative input voltage the third power switch is constant off and the fourth power switch is conducting when the second power switch is in an off period.

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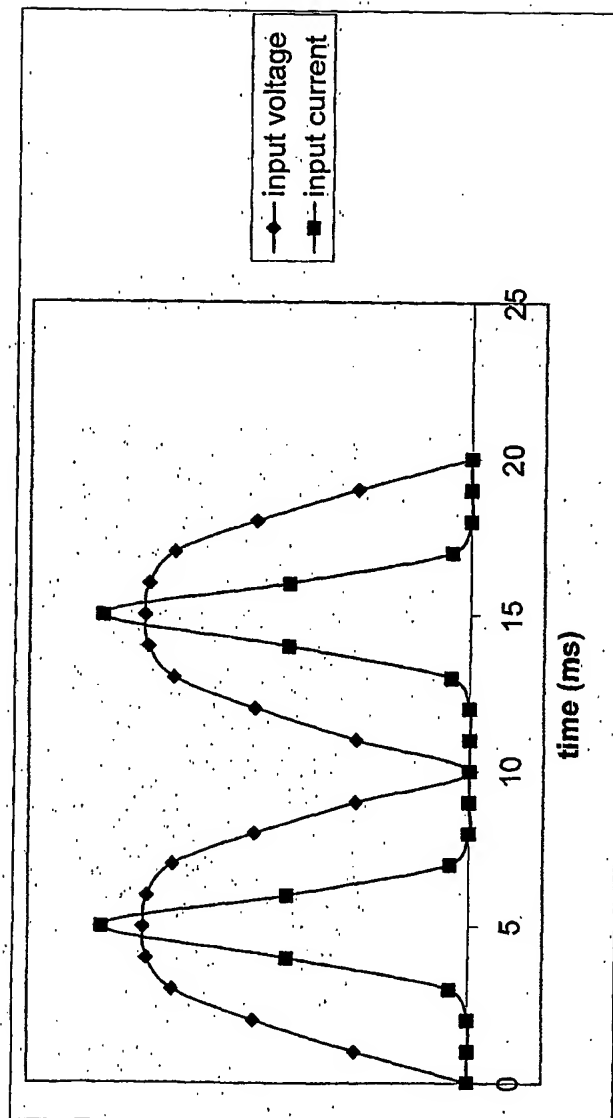


Fig. 1



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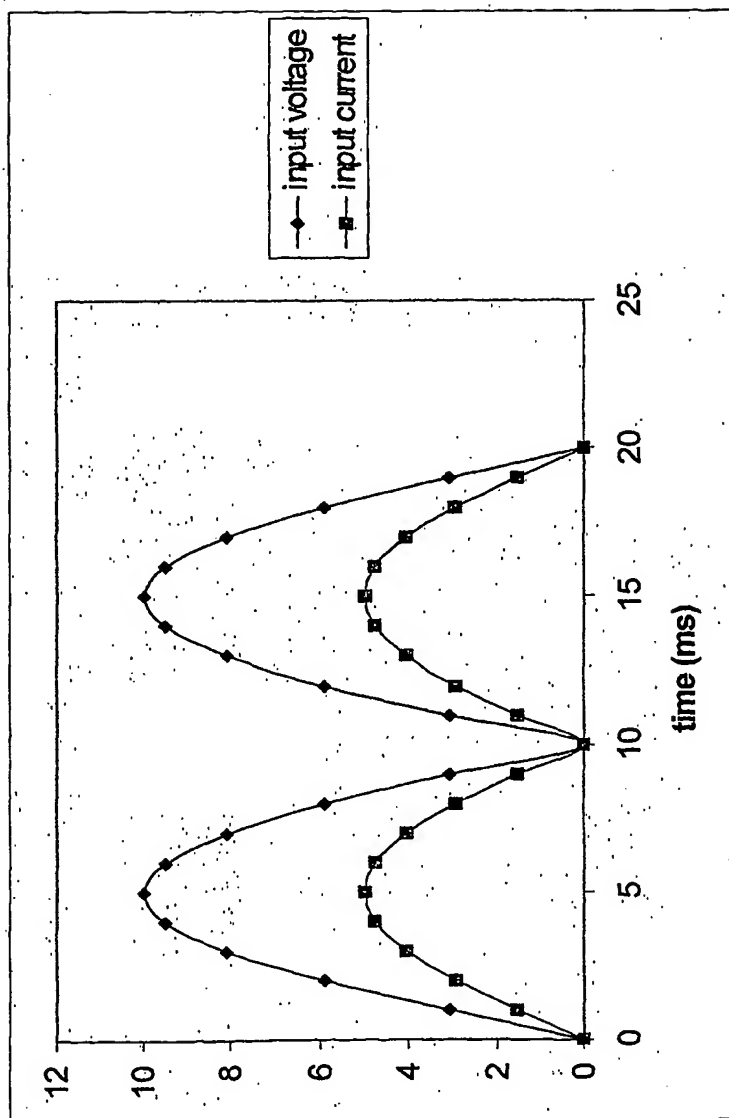


Fig. 2

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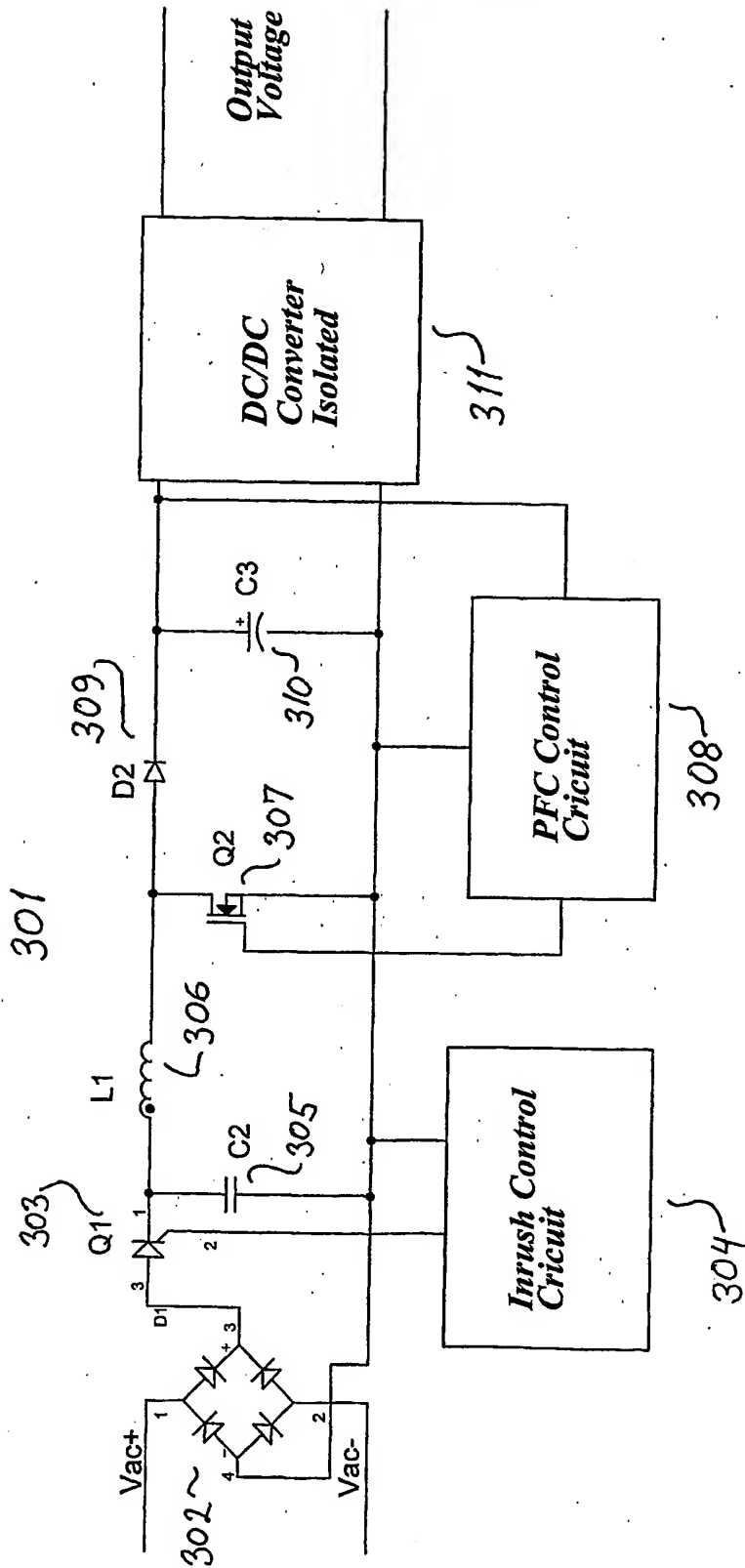


Fig. 3

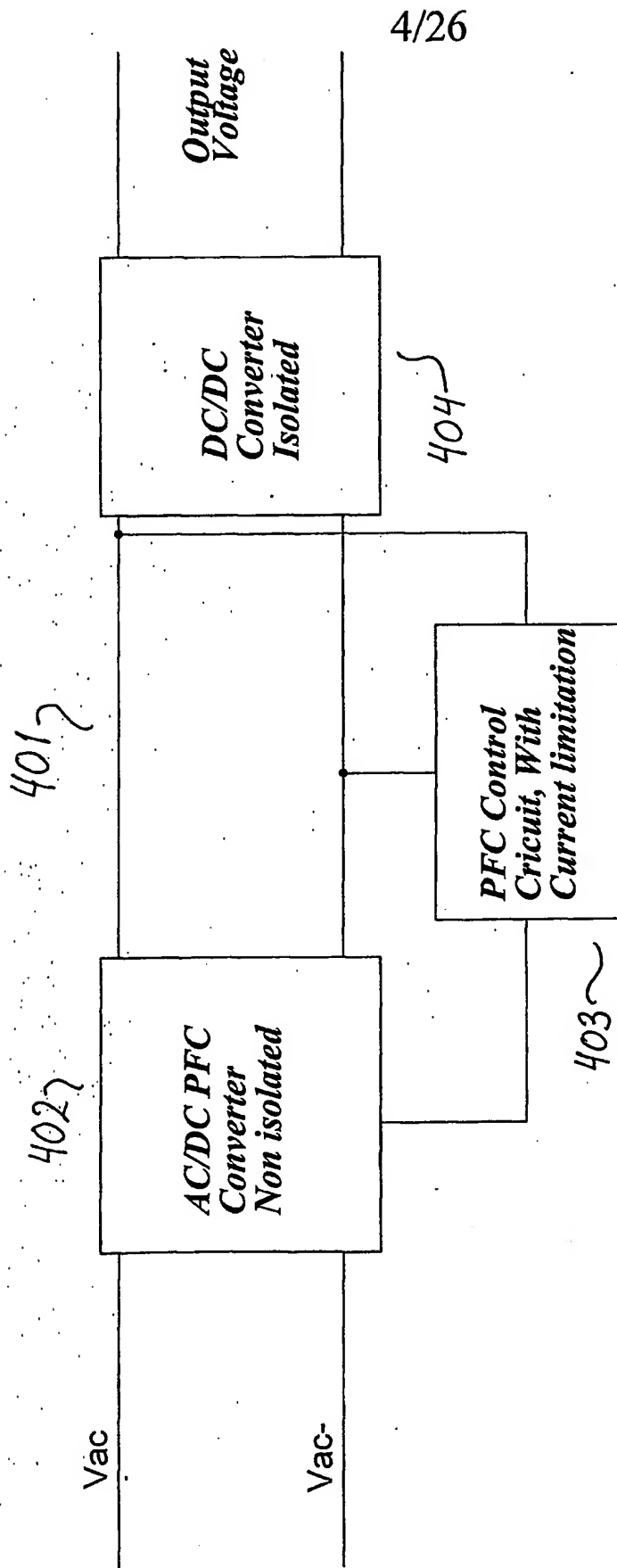


Fig. 4

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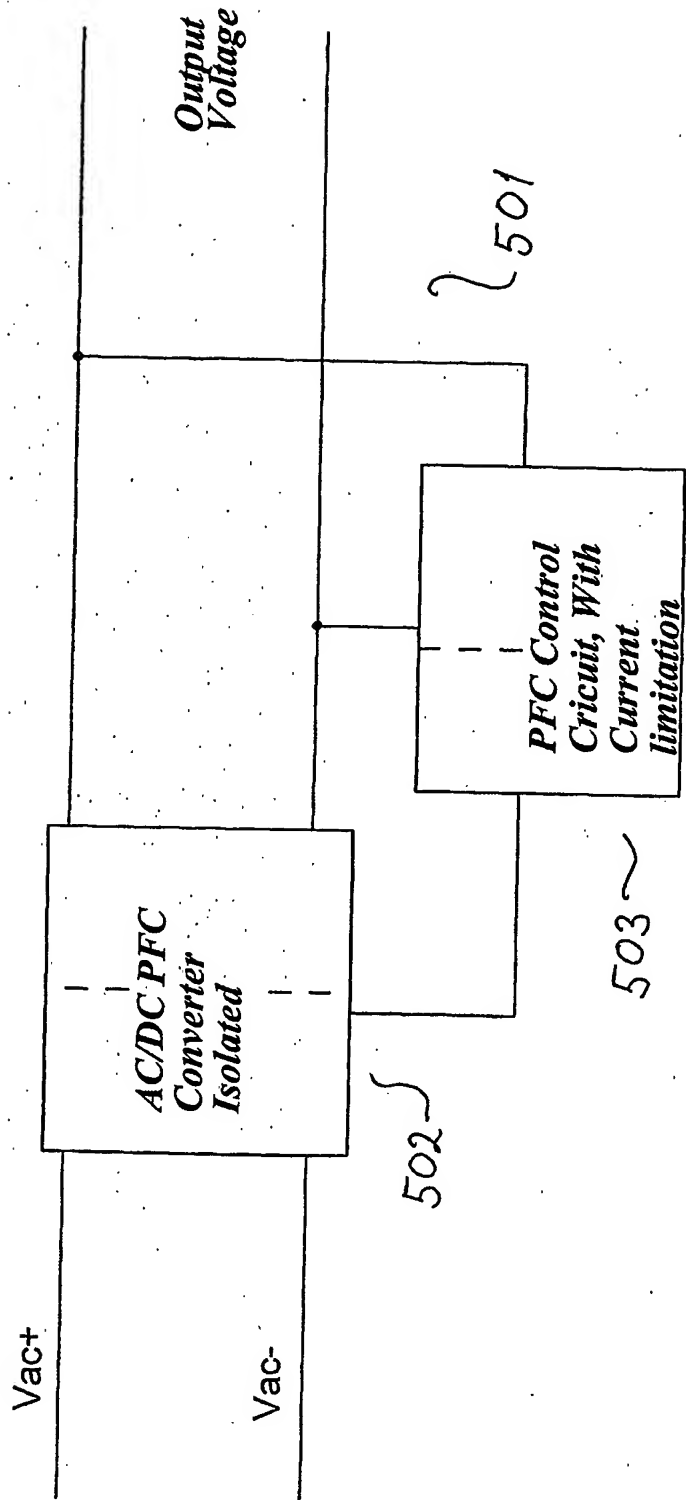


Fig. 5

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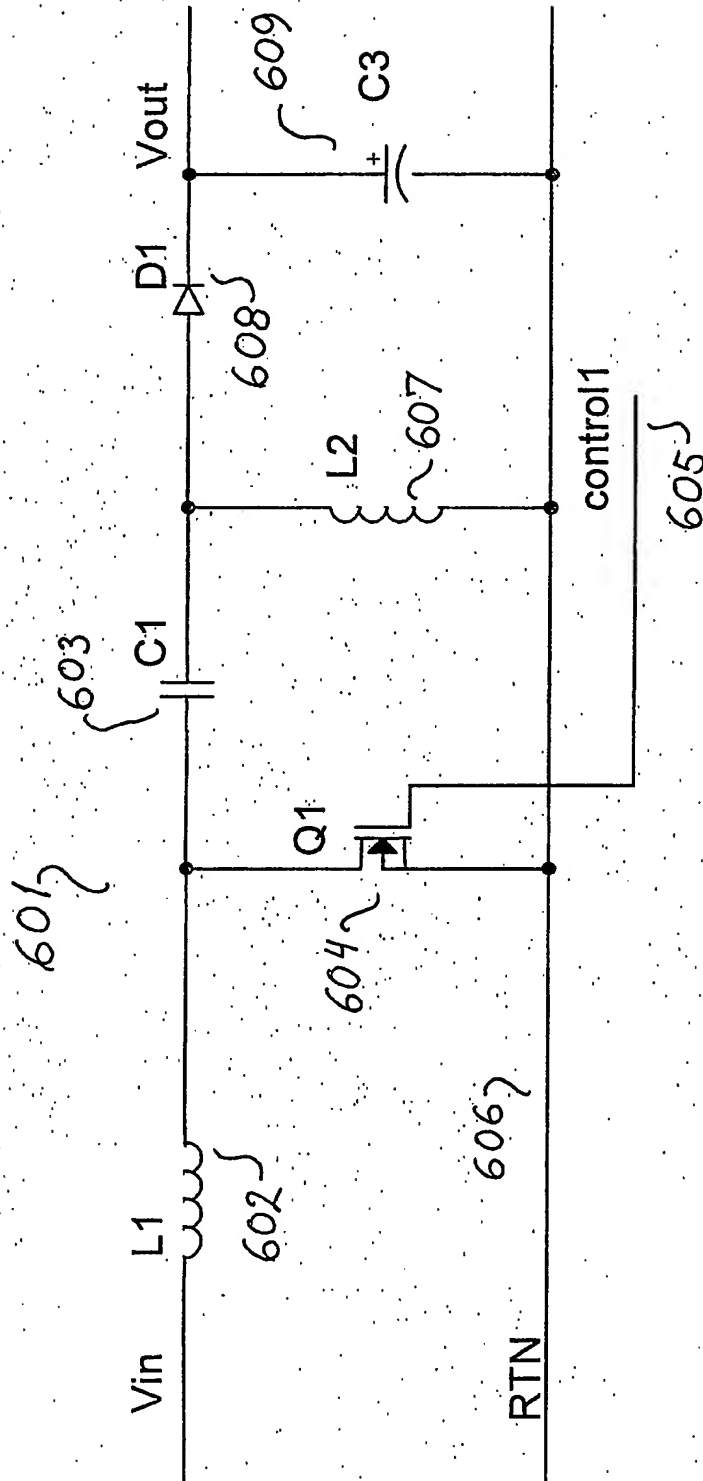


Fig. 6

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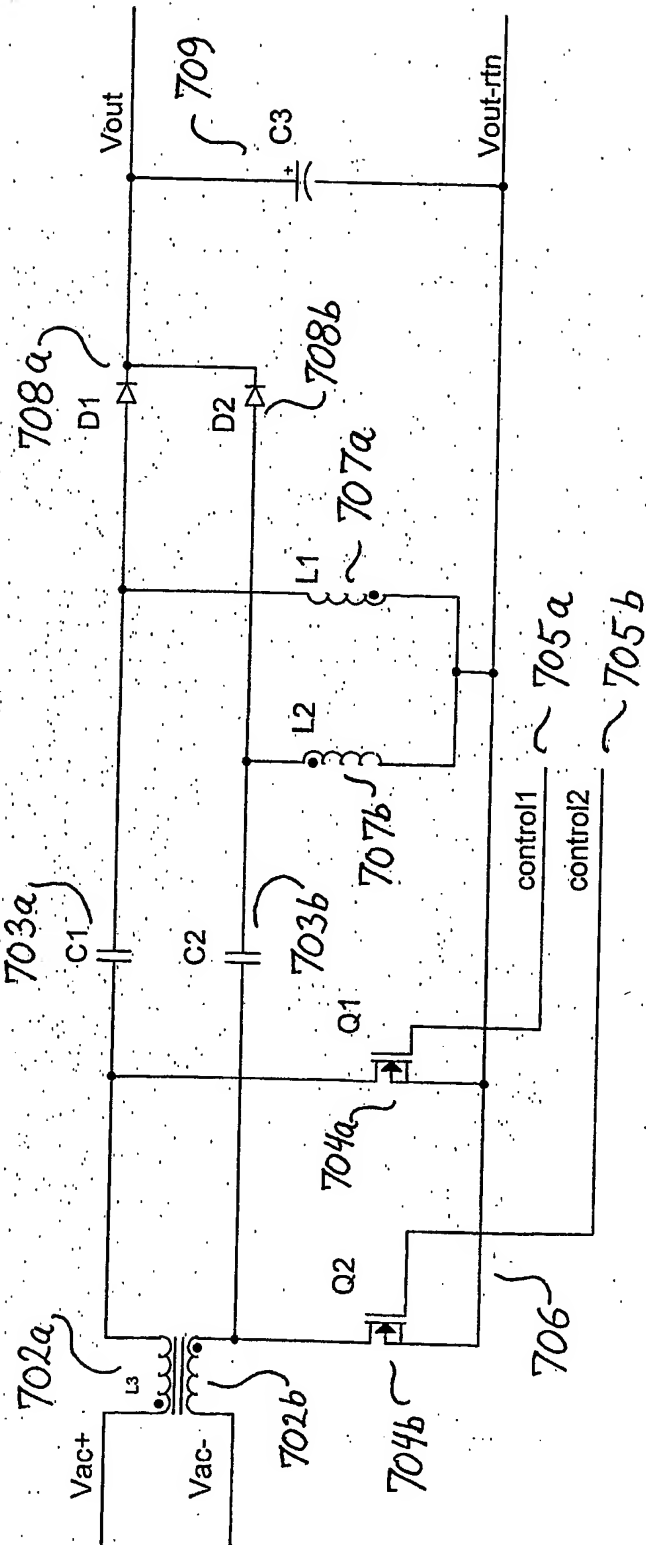


Fig. 7

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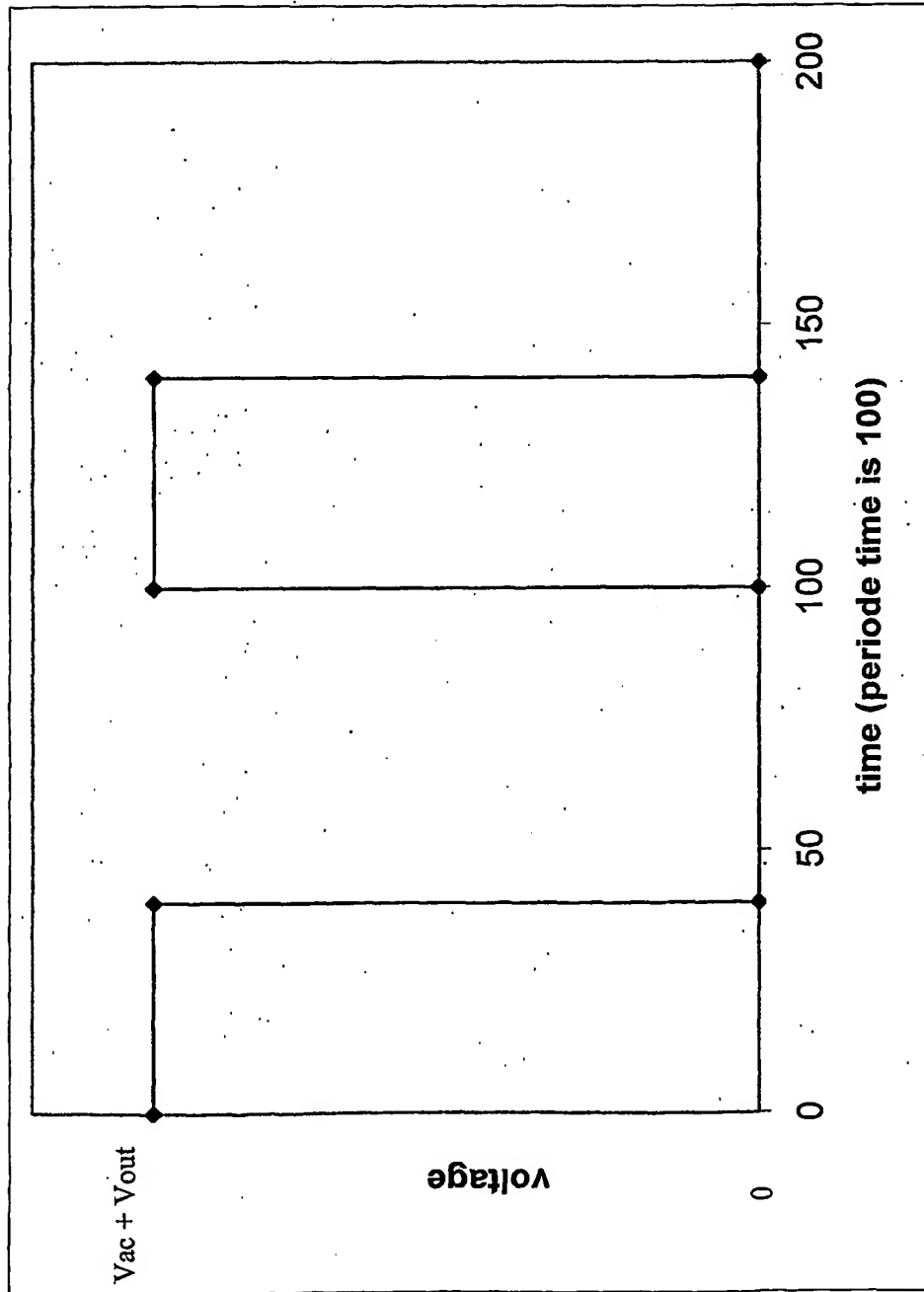


Fig. 8a

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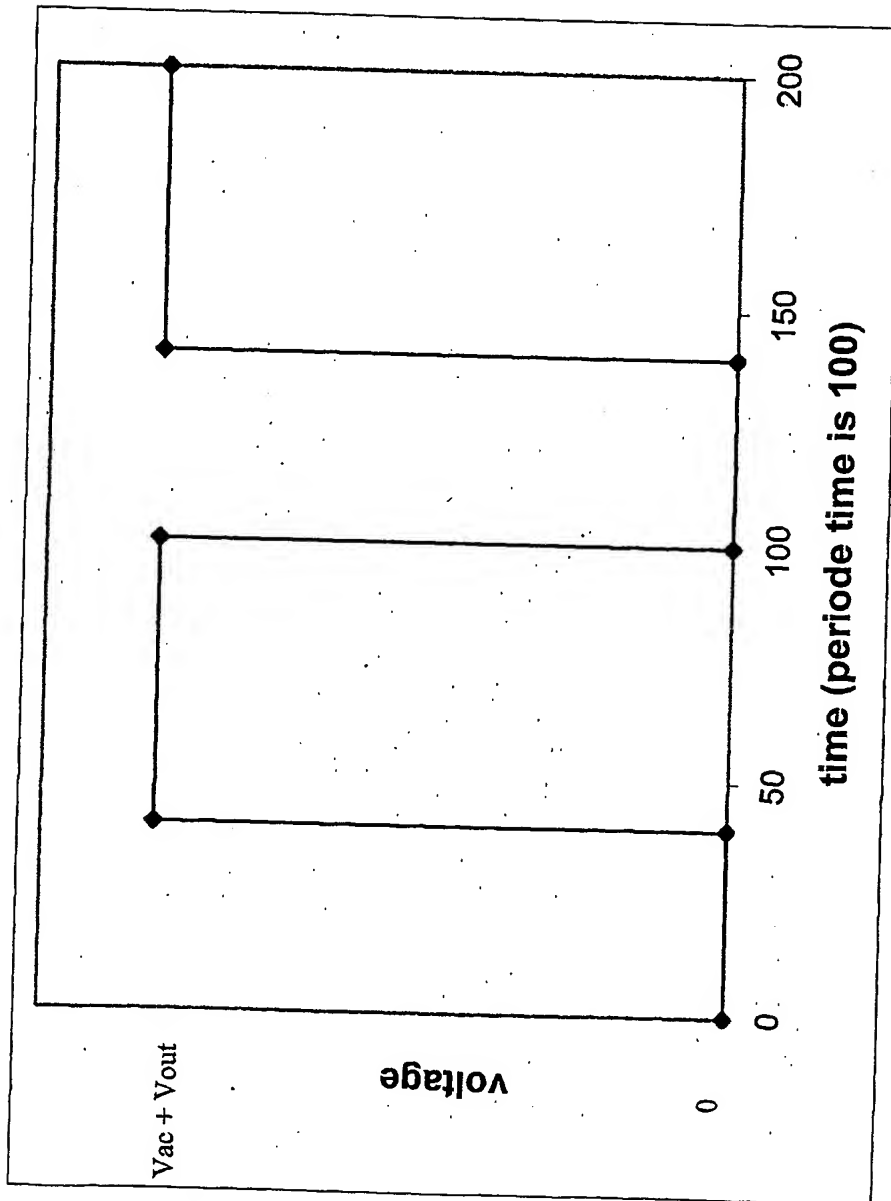


Fig. 8b



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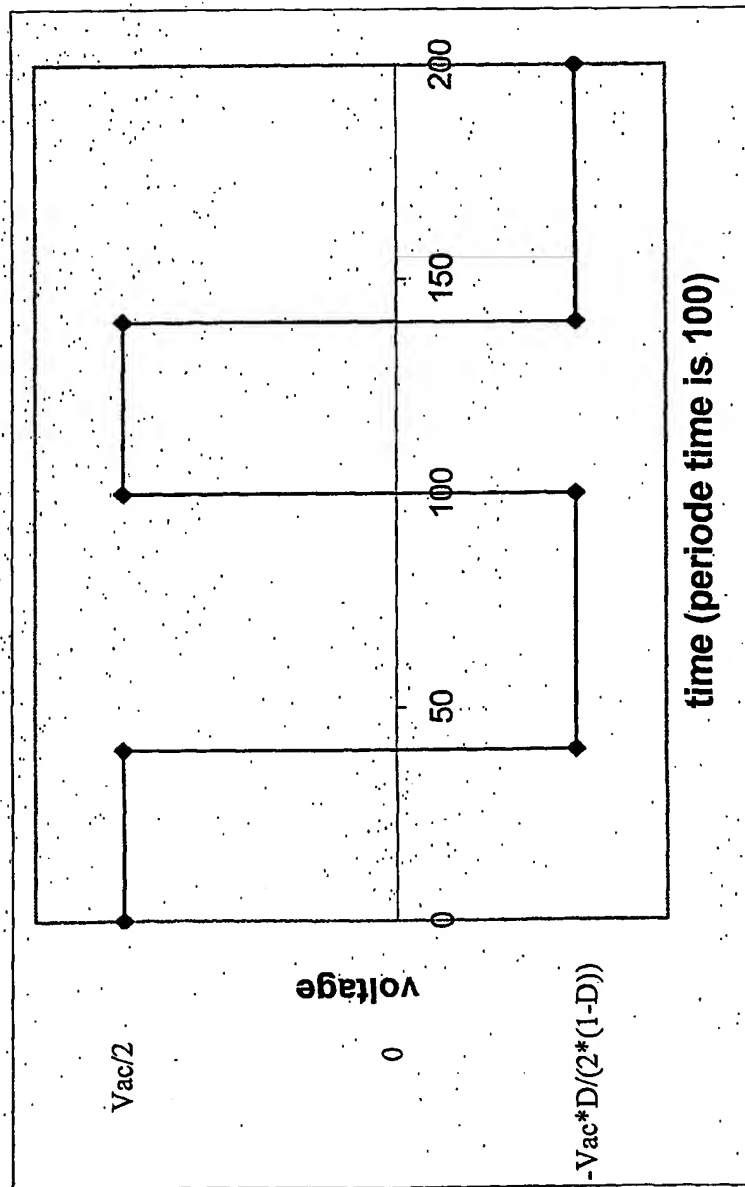


Fig. 8c

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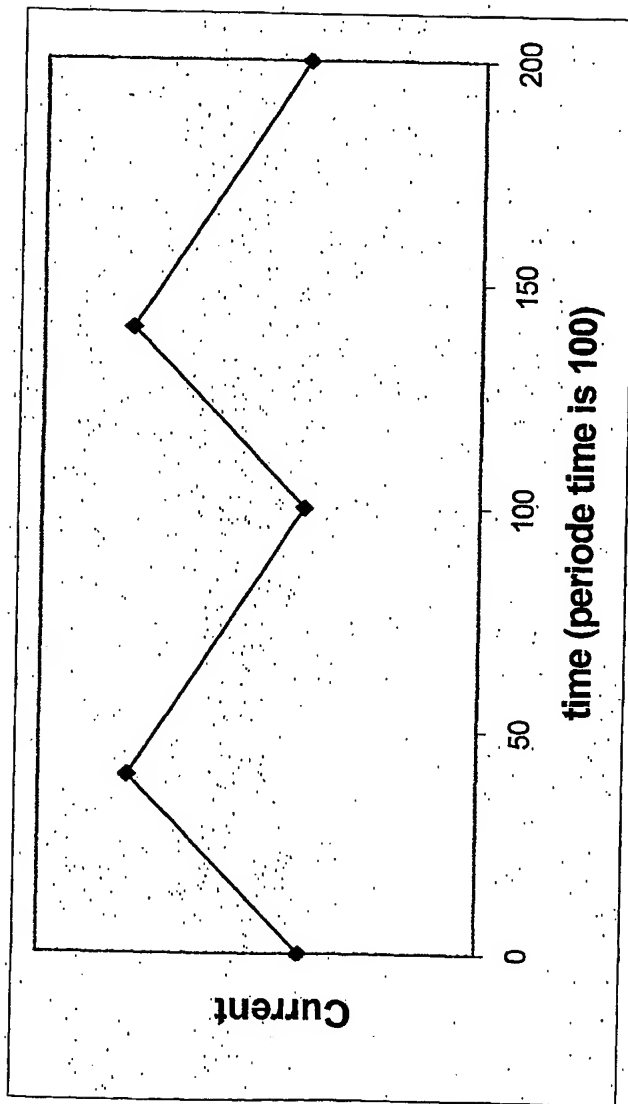


Fig. 9

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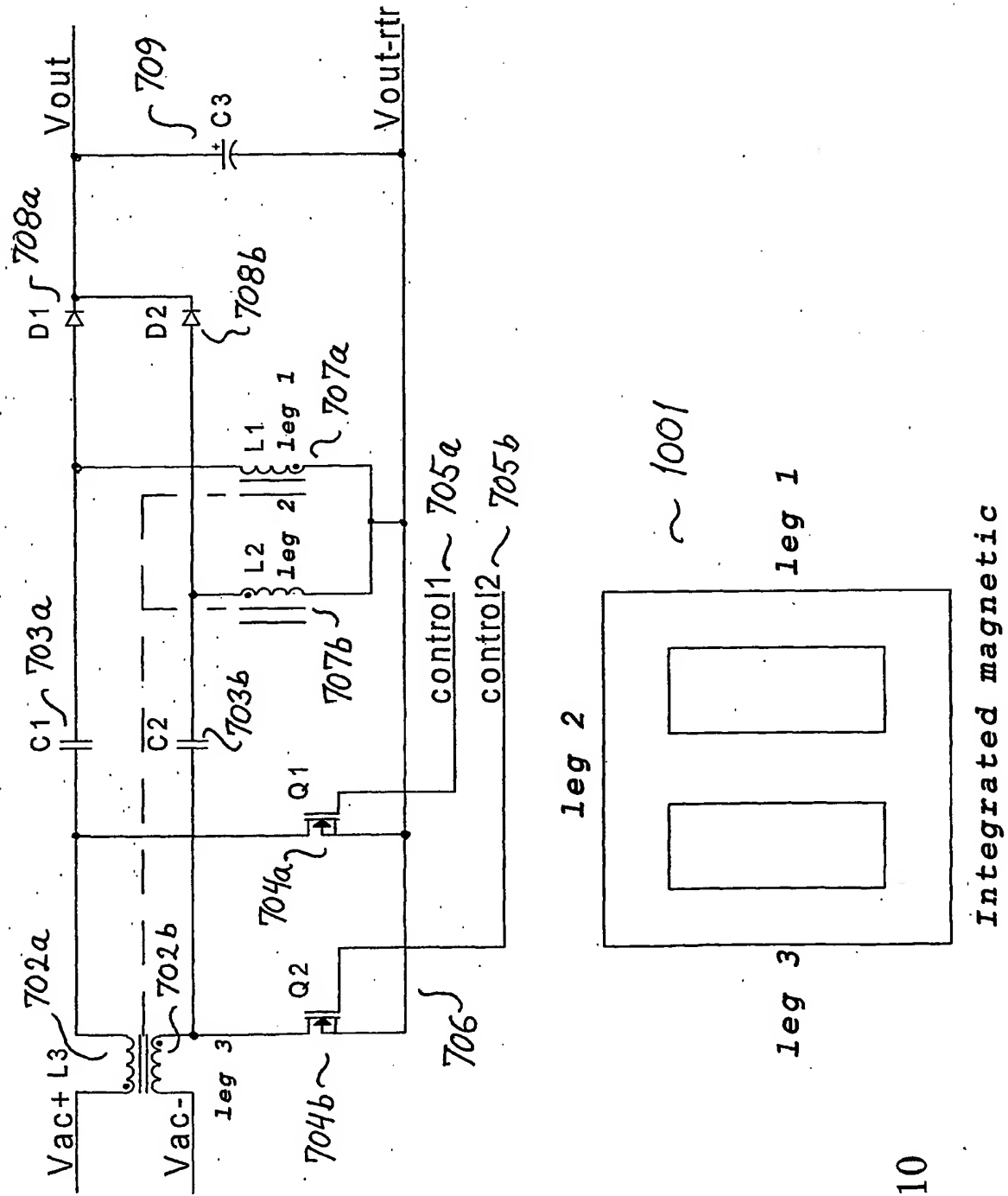


Fig. 10

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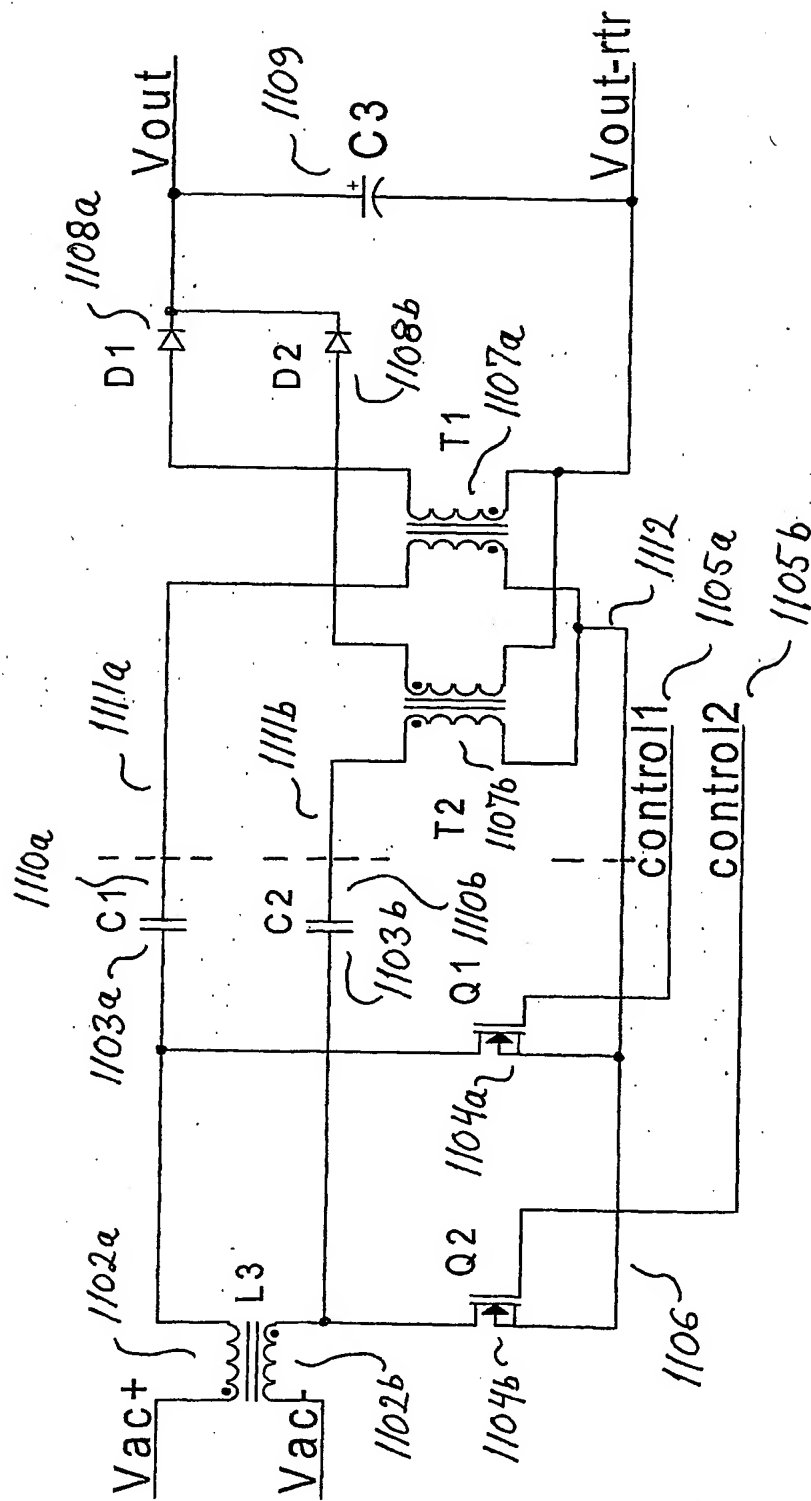


Fig. 11

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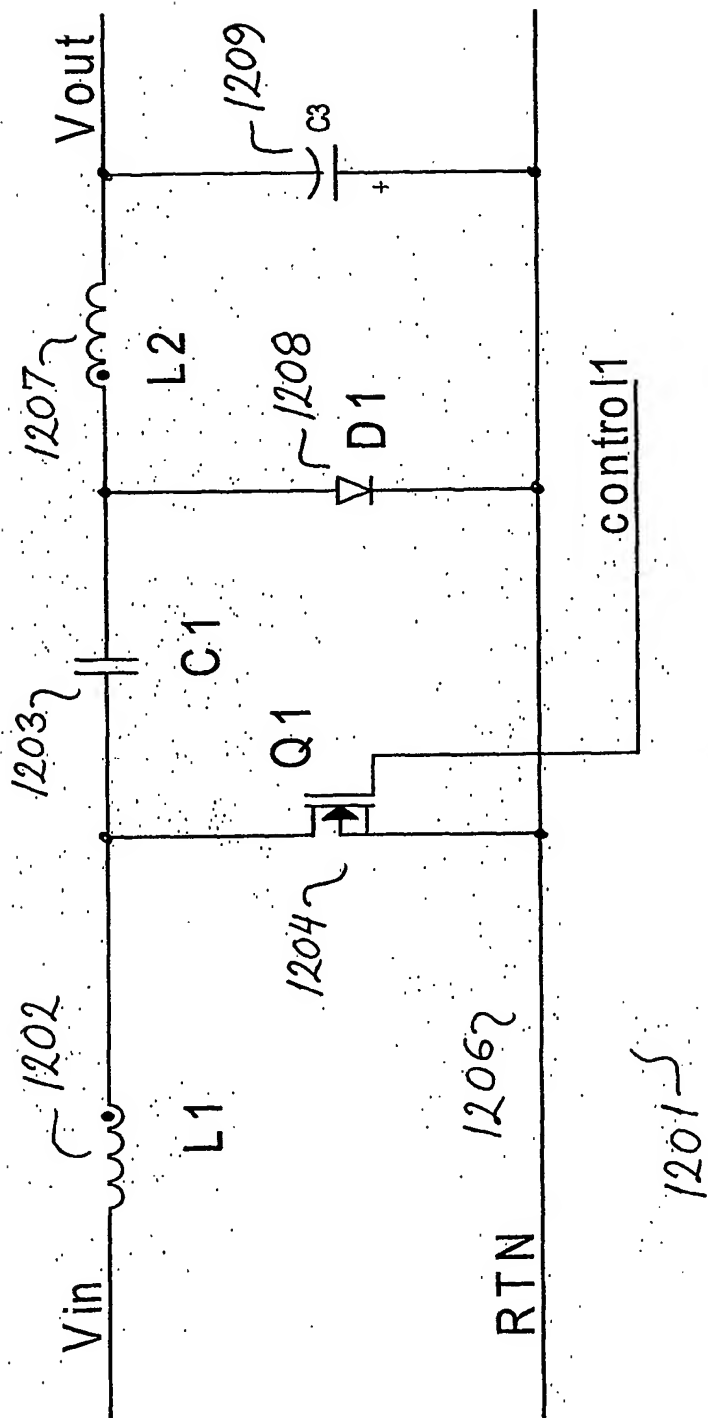


Fig. 12

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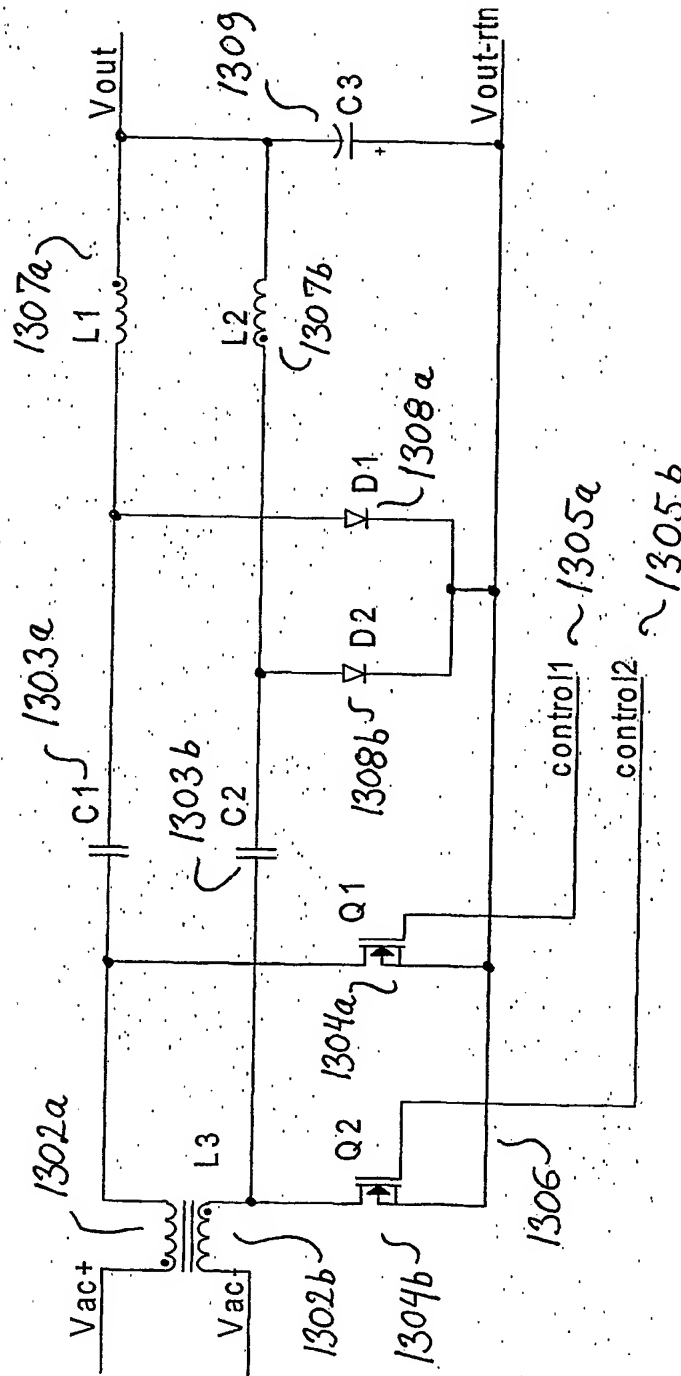


Fig. 13

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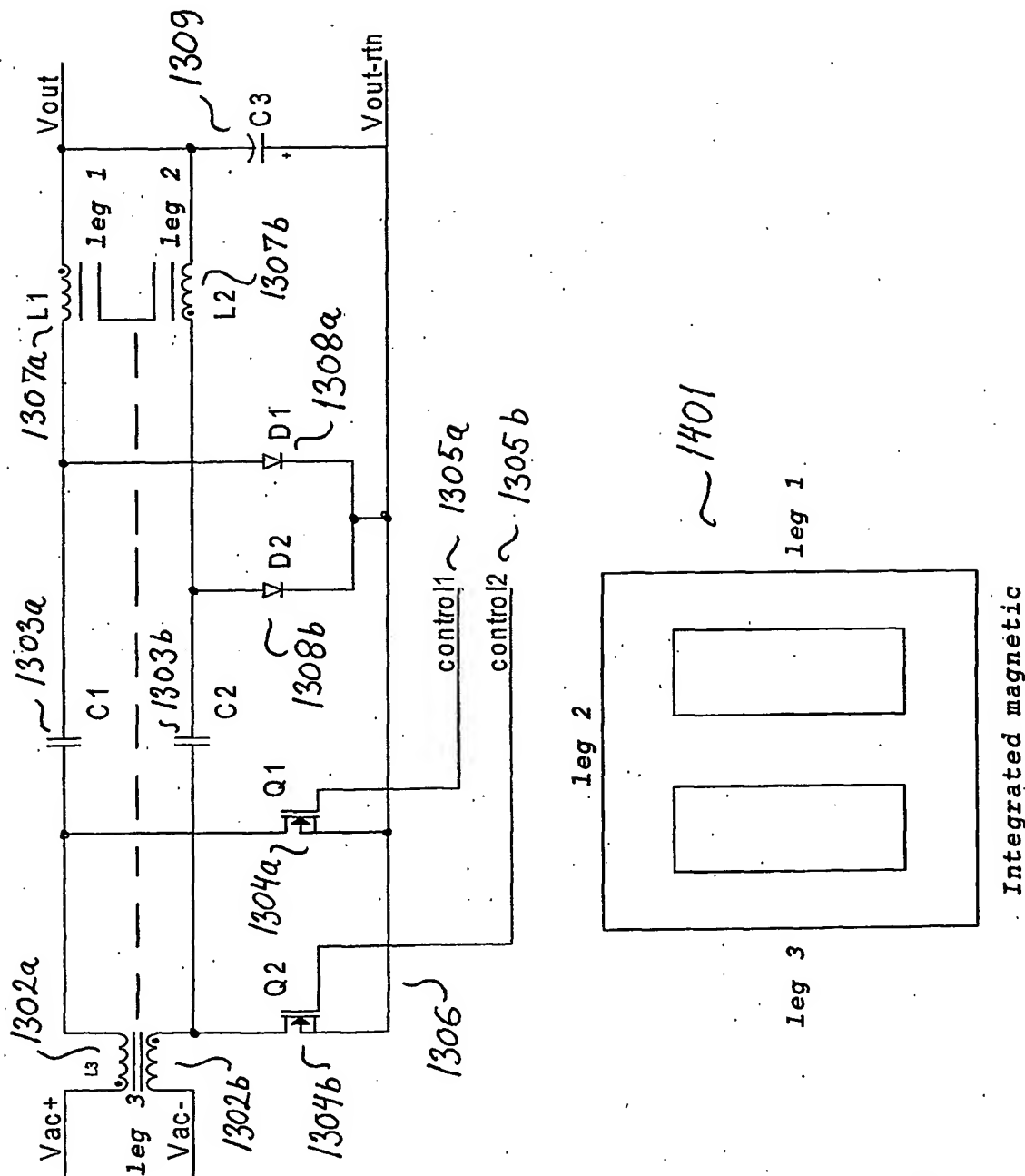


Fig. 14

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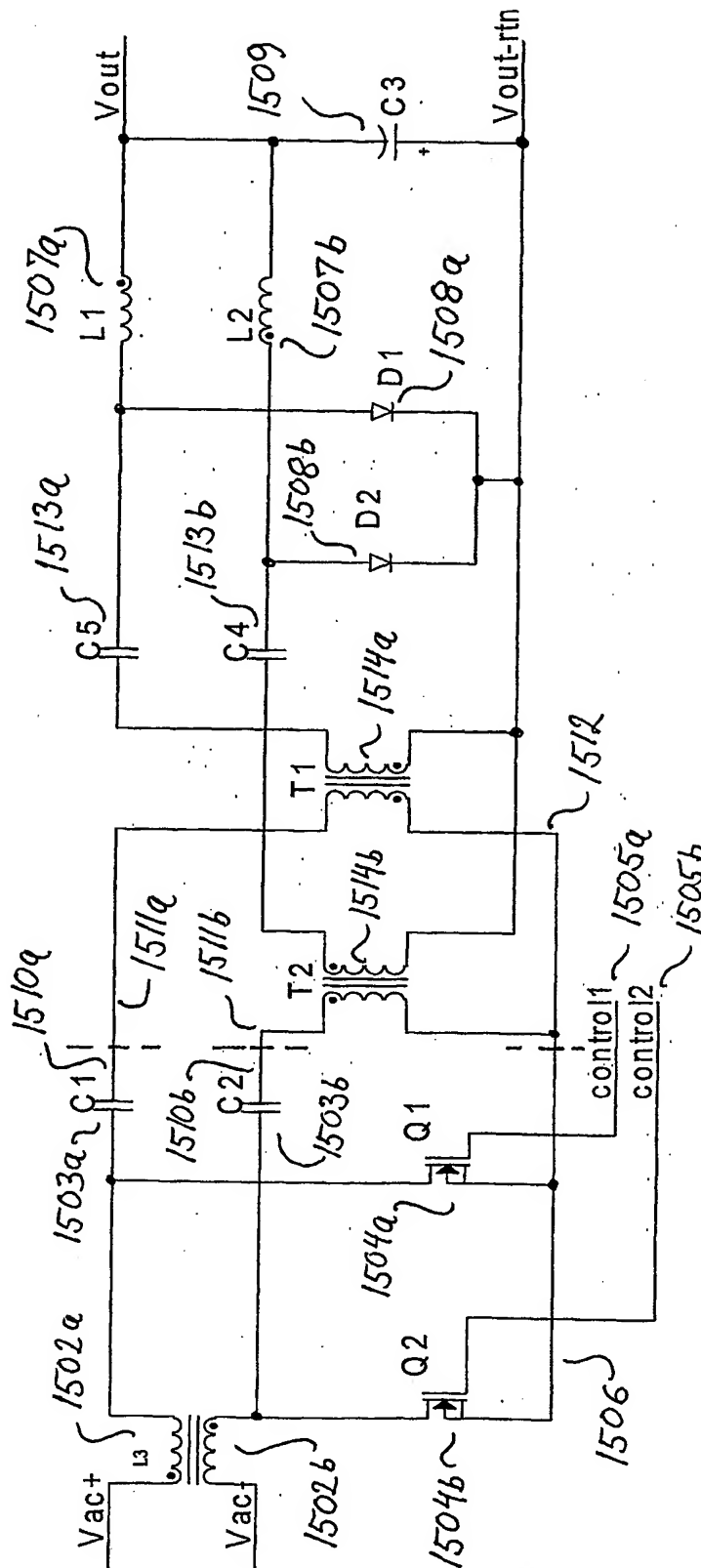


Fig. 15



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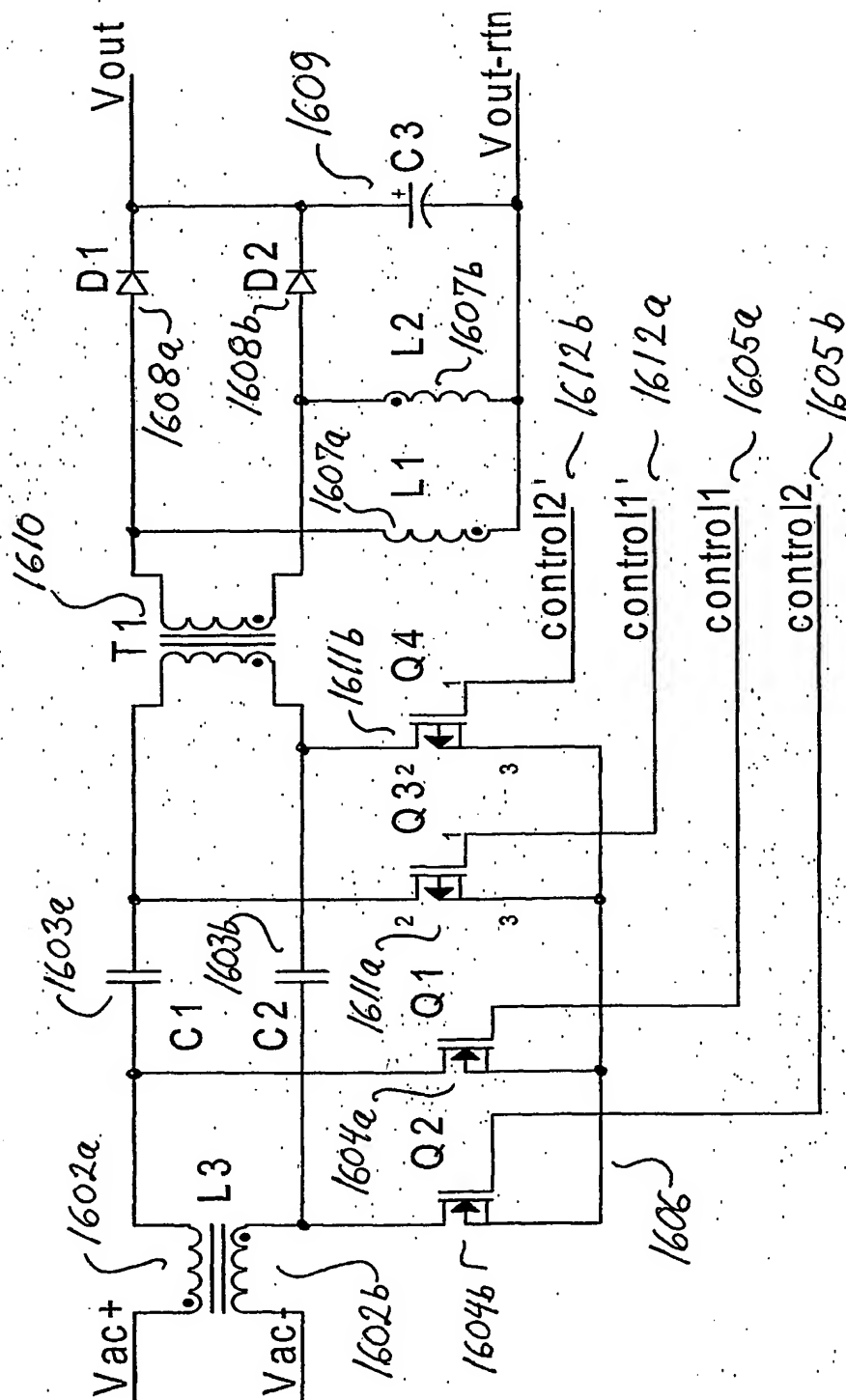


Fig. 16

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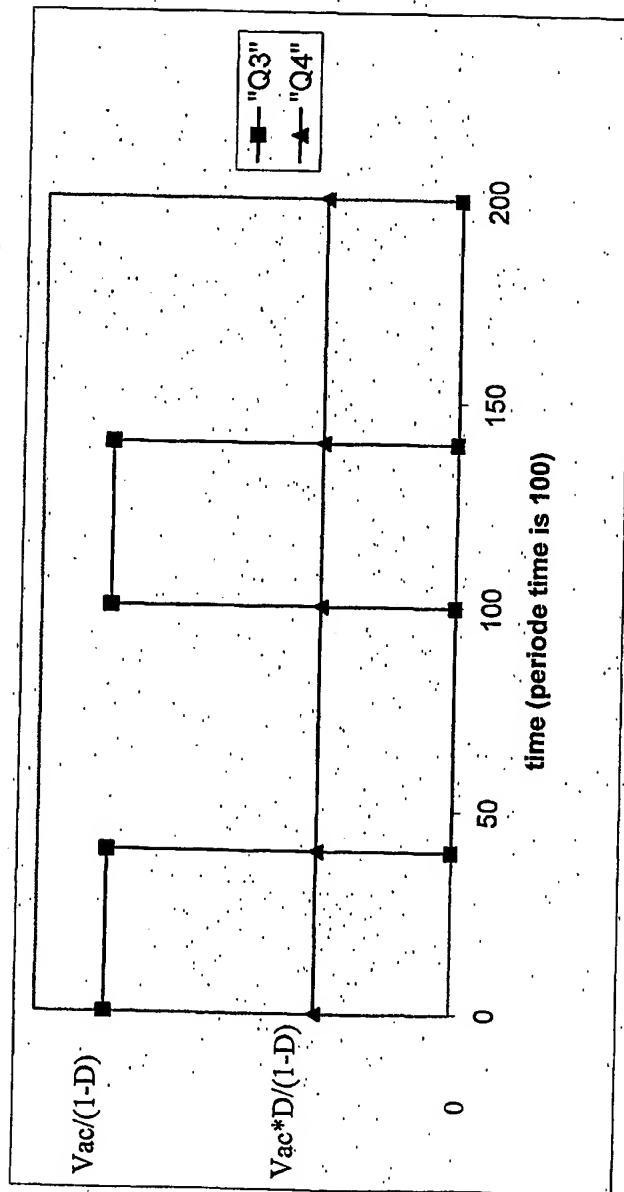


Fig. 17a

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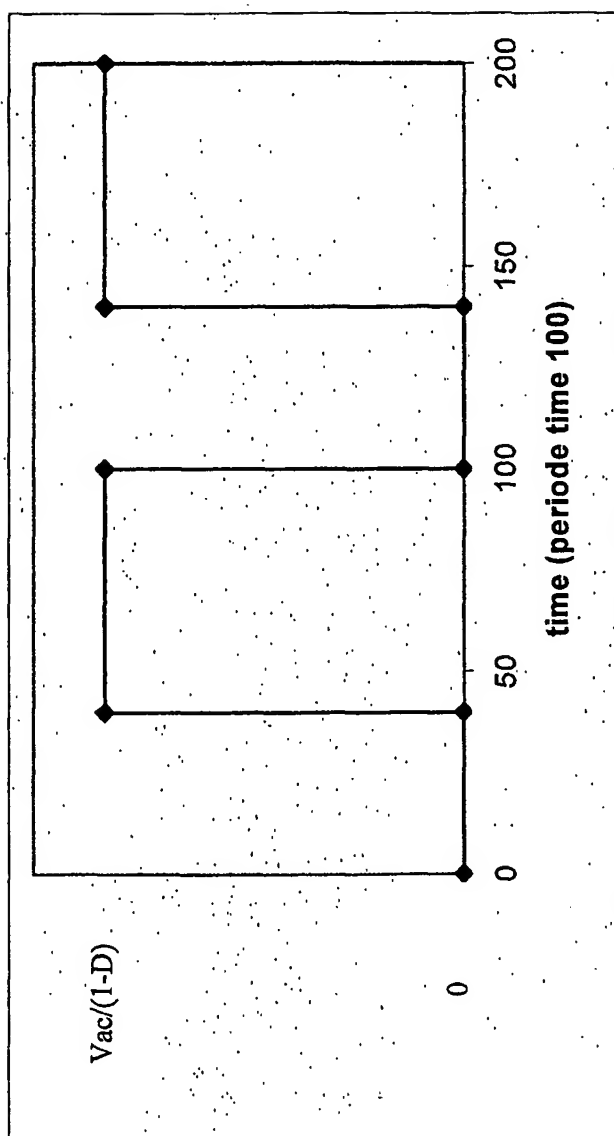


Fig. 17b

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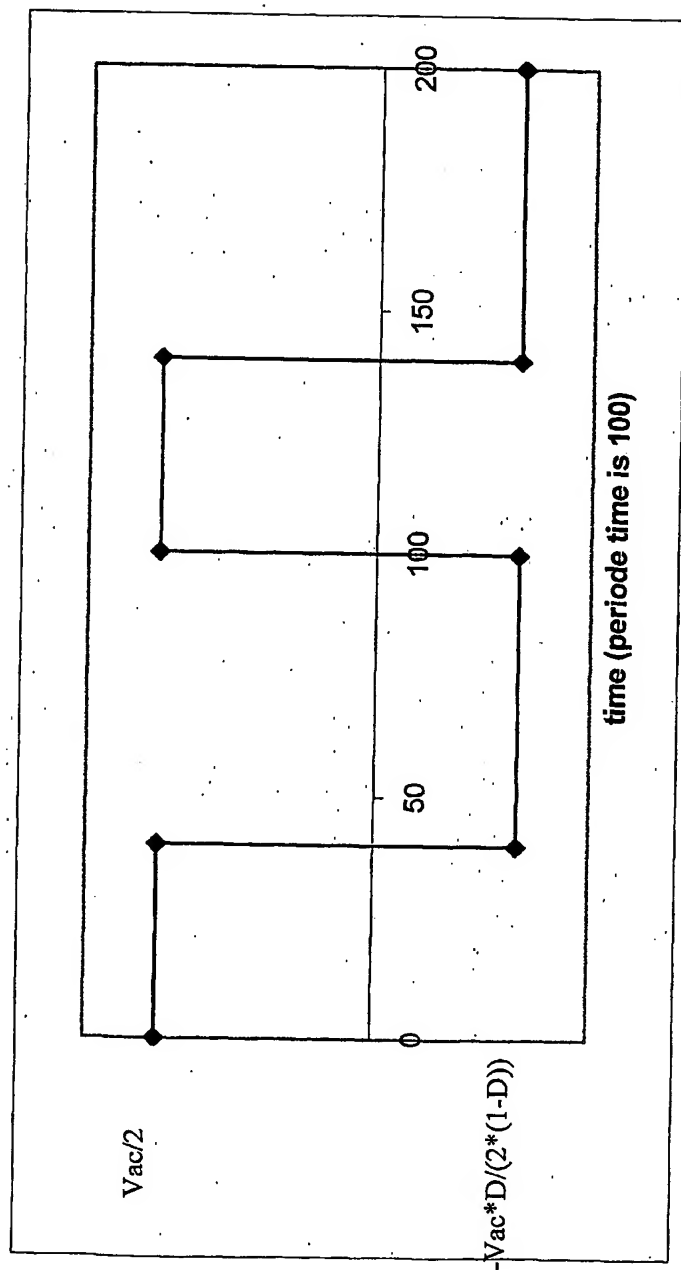


Fig. 17c

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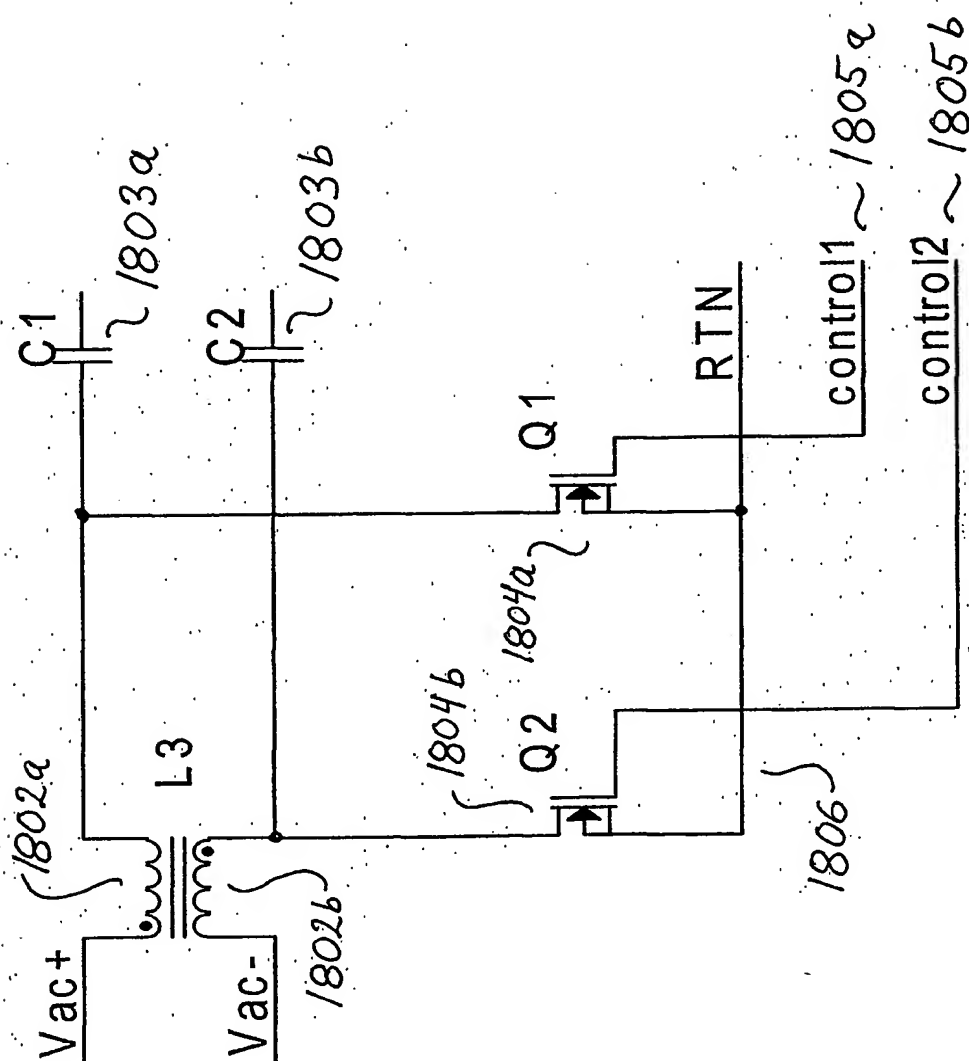


Fig. 18

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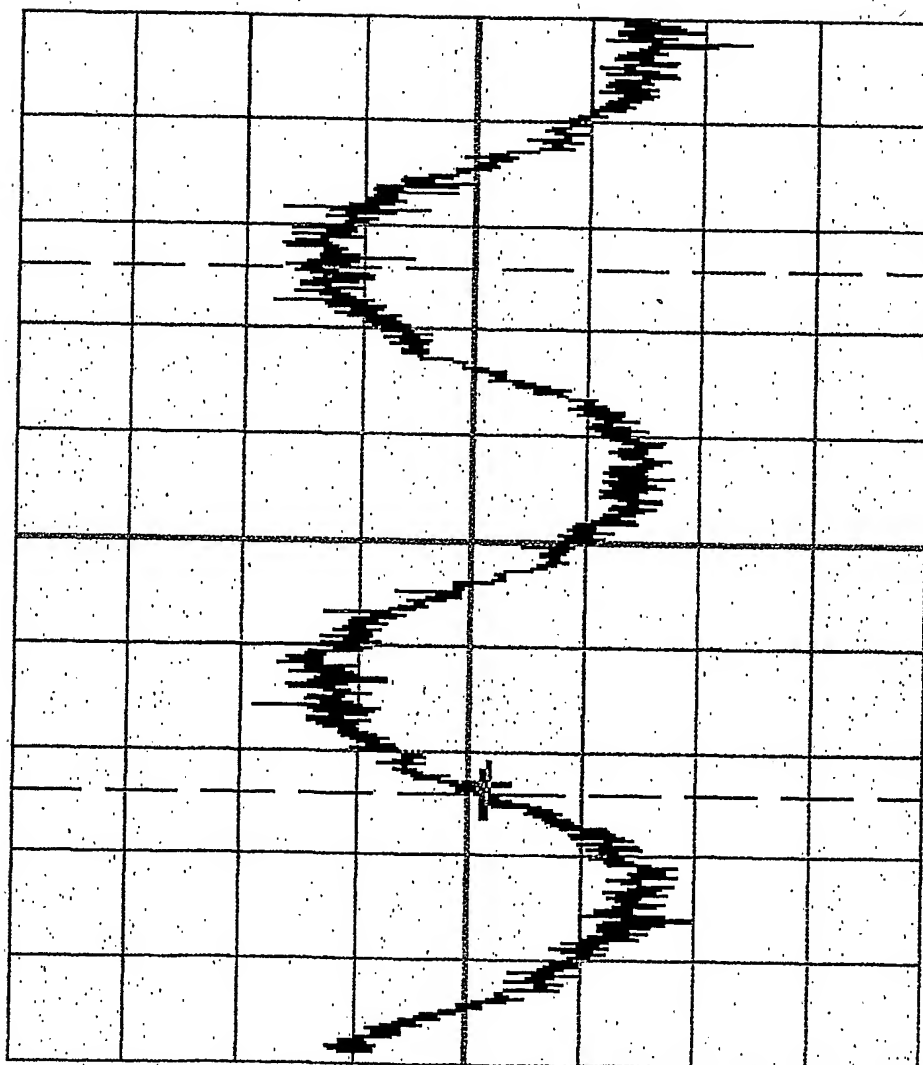


Fig. 19

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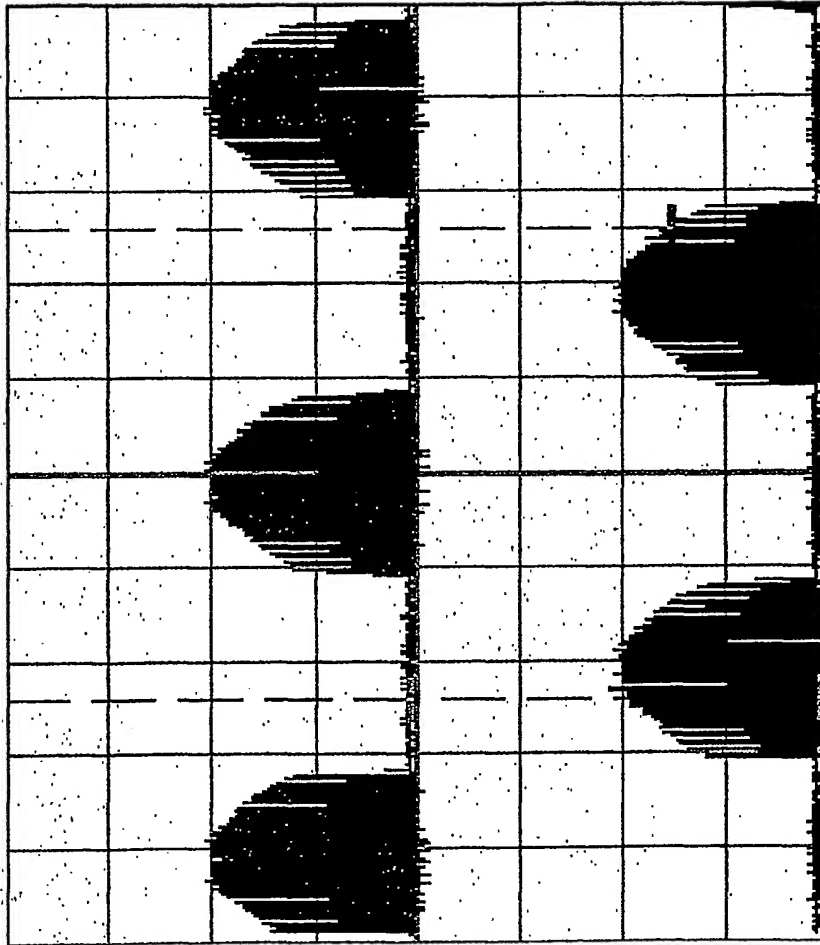


Fig. 20

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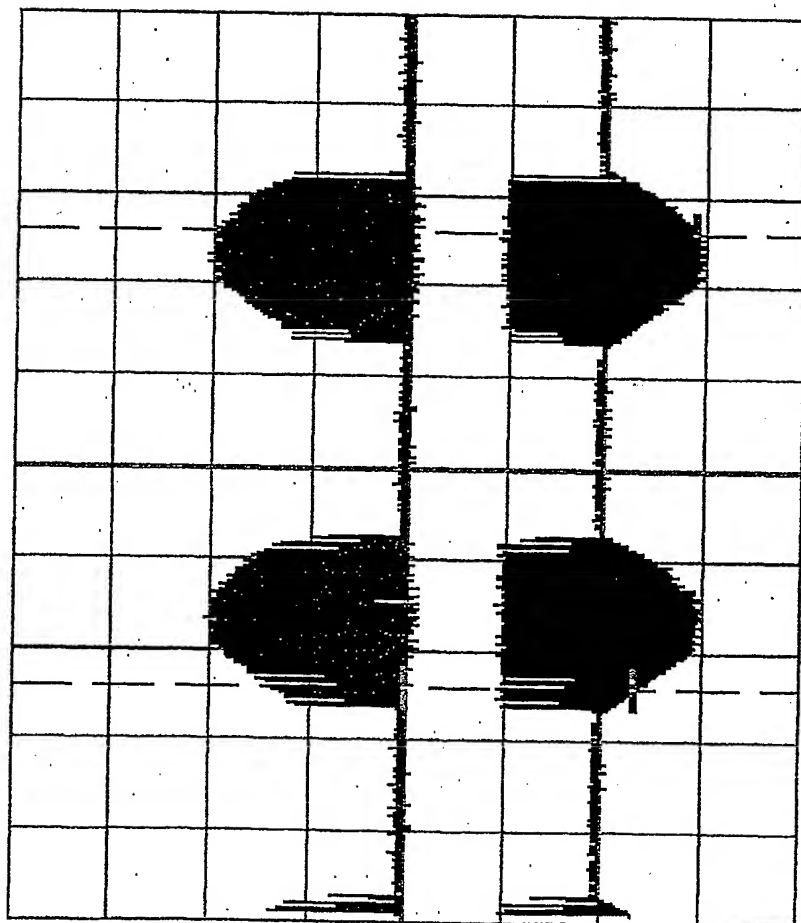


Fig. 21



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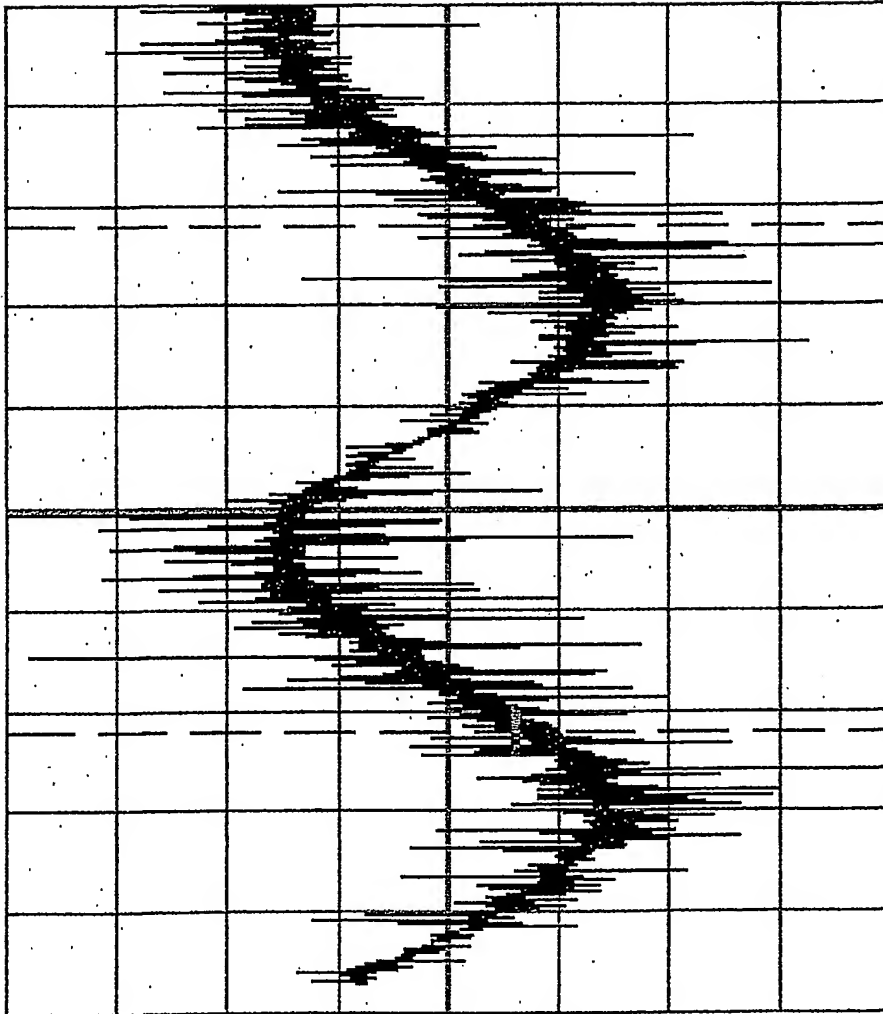


Fig. 22

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/DK 02/00272

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC 7 H02M7/217 H02M1/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ALEXANDRE FERRARI DE SOUZA: "high power factor rectifier with reduced conduction and commutation losses." IEEE, 6 June 1999 (1999-06-06), pages 1-5, XP000868412 figures 1-8	1,3
Y	US 5 442 539 A (SLOBODAN CUK ET AL.) 15 August 1995 (1995-08-15) abstract figures 2,4	1,3
A	US 4 412 277 A (DANIEL M. MITCHELL) 25 October 1983 (1983-10-25) abstract figure 1	1,3
	--- -/-	



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

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Date of the actual completion of the international search

7 August 2002

Date of mailing of the international search report

14/08/2002

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## INTERNATIONAL SEARCH REPORT

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ILKKA LINDROTH ET AL.: "Methods of improving efficiency in wide input range boost converters at low input voltages" IEEE, 10 September 2000 (2000-09-10), pages 424-431, XP000968730 figure 5	1,3
A	US 6 115 267 A (EDWARD HERBERT) 5 September 2000 (2000-09-05) cited in the application abstract figure 2	1,3
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A	WO 01 03279 A (ADVANCED ENERGY INDUSTRIES) 11 January 2001 (2001-01-11) figures 1-8, 3-3, 3-5	1,3
A	US 5 283 726 A (ALAN W. WILKERSON) 1 February 1994 (1994-02-01) figure 8 column 19, line 8 - line 16	1,3
P,X	US 6 282 109 B1 (SIMON FRAIDLIN ET AL.) 28 August 2001 (2001-08-28)  the whole document	1-5, 8-11, 14, 15, 20-23

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